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Book of
Abstracts

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Wednesday, September 2

8:30 – 10:00	Registration with welcome coffee
10:00 – 10:15	Opening ceremony

Session 1 (chairman: Mato Knez)	
10:15 – 10:45	Tamar Segal Peretz (invited) , <i>Technion- Israel Institute of Technology, Israel</i> To Infiltrate or Not to Infiltrate? Designing Hybrid Materials with VPI, ALD, and MLD
10:45 – 11:15	Mark Losego (invited) , <i>Georgia Institute of Technology, USA</i> Approaches for Elucidating the Physicochemical Structure of Organic-Inorganic Hybrids Synthesized via Vapor Infiltration of Polymers
11:15 – 11:45	Michael Nolan (invited) , <i>University College Cork, Ireland</i> Mechanisms of Hybrid Atomic Level Processing
11:45 – 12:00	Helle-Mai Piirsoo , <i>Institute of Electrical Engineering, Slovakia</i> Residual Gas Analysis of Atomic Layer Deposition on Powders

12:00 – 13:30	Lunch break
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Session 2 (chairman: Iva Šarić Janković)	
13:30 – 14:00	Gabriele Seguinì (invited) , <i>IMM-CNR, Unit of Agrate Brianza, Italy</i> Sequential Infiltration Synthesis for Organized Nanostructure Fabrication
14:00 – 14:30	John Conley (invited) , <i>Oregon State University, USA</i> Microwave Enhanced Atomic Layer Processing
14:30 – 14:45	Zsófia Baji , <i>Centre for Energy Research, Hungary</i> Precursor–Surface Interactions Governing ALD: A DFT Study of Hf Precursors and Co-Reactants on MoS ₂
14:45 – 15:00	Dea Fackovic Volcanjk , <i>Stanford University, USA</i> Sequence Matters: Tailoring Al- and Hf-Based Oxide Dielectrics on Monolayer MoS ₂
15:00 – 15:15	Jean-Francois de Marneffe , <i>imec, Belgium</i> Plasma etching for defectivity reduction: the example of TiO ₂ area-selective deposition

15:15 – 15:45	Coffee break
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PROGRAM

Session 3 (chairman: David Bergsman)	
15:45 – 16:00	Wenwen Wang , <i>CIC nanoGUNE, Spain</i> Hybrid metallosaccharide films for protecting wood from environmental damage
16:00 – 16:30	Alex B. F. Martinson (invited) , <i>Argonne National Laboratory, USA</i> Vapor Deposition of Molecularly Defined Multi-Metal Clusters for Energy Conversion and Photocatalysis ONLINE

Session 4 (chairman: Tamar Segal-Peretz)	
16:30 – 17:00	Ruoke Cai (invited) , <i>Israel Institute of Technology, Israel</i> Molecular Layer Deposition of Polyamide Membranes for Selective Water and Ion Transport
17:00 – 17:30	Harpreet Sondhi (invited) , <i>University of Twente, Netherlands</i> Atomic and molecular layer deposition engineered ceramic membranes for nanofiltration and solvent-resistant nanofiltration
17:30 – 18:00	Jolke Perelaer (invited) , <i>Wiley-VCH GmbH, Germany</i> Wiley workshop: How to publish in high-impact (factor) journals?

18:00 – 20:00	Poster session and social program
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P1	Zsófia Baji , <i>Centre for Energy Research, Hungary</i> Hybrid Hafnicon Thin Films for Moisture-Responsive Dielectric Applications
P2	Ofer Burg , <i>The Hebrew University of Jerusalem, Israel</i> Towards Bimetallic Nanowire Arrays with Controlled Compositions Using Block Copolymer Films: The Interplay Between Metal Precursors
P3	Yumei Chai , <i>CIC nanoGUNE, Donostia/San Sebastián, Spain</i> Introducing Chemical Vapor Etching (CVE) as Material-Selective Approach for Surgically Precise Tarnish Removal from corroded bronze surfaces
P4	Teresa Elenes-Cervantes , <i>Instituto de Microelectrónica de Barcelona, Spain</i> Vapor Phase Infiltration in PS-b-PMMA Thin Films: Role of Morphology and Temperature
P5	Slim Hussein , <i>Centre National de la Recherche Scientifique, France</i> Vapor Phase Infiltration for SWCNT Filling
P6	Daria Jardas Babić , <i>University of Rijeka, Faculty of Physics, Croatia</i> Solar-Driven Caffeine Degradation Using Porous Cu _x O/Al ₂ O ₃ /ZnO Heterojunction Films
P7	Ivana Jelovica Badovinac , <i>University of Rijeka, Faculty of Physics, Croatia</i> Atomic Layer Deposition of Hybrid TiO ₂ -Cu Nanocomposites for Solar Photocatalysis
P8	Ivna Kavre Piltaver , <i>University of Rijeka, Faculty of Physics, Croatia</i> Enhanced Solar-Light Photocatalysis of Cu-Doped ZnO Thin Films on Self-Ordered Porous Anodized Substrates

PROGRAM

P9	Maria Kolympadi Markovic, <i>University of Rijeka, Faculty of Physics, Croatia</i> Solution- and Vapor-phase Synthetic Approaches to Immobilized Metal-Organic Frameworks (MOFs)
P10	Noam Lerner, <i>Israel Institute of Technology, Israel</i> Reaction–Diffusion Modelling of Vapor Phase Infiltration in Block Copolymer Thin Films
P11	Mattea Mačkić Jovanović, <i>University of Rijeka, Faculty of Physics, Croatia</i> Growth Temperature-Dependent Microstructural Properties of SnO ₂ Thin Films Deposited by ALD and PEALD
P12	Shani Monadeev, <i>Israel Institute of Technology, Israel</i> Promoting the synthesis of sustainable aviation fuels (SAFs) over exposed heterointerfaces
P13	Sara Pakseresht, <i>Aalto University, Finland</i> Atomic Layer Deposition for Stabilizing Lithium Metal Interfaces in Next-Generation Lithium Batteries
P14	Robert Peter, <i>University of Rijeka, Faculty of Physics, Croatia</i> ZnO Thin Films with Embedded Copper Nanoparticles as Plasmonic Photocatalysts for Solar-Driven Wastewater Treatment
P15	Iva Šarić Janković, <i>University of Rijeka, Faculty of Physics, Croatia</i> Plasma-Assisted ALD/MLD of SiOTiNC Hybrid Ultrathin Films from Cyclic Tetrasiloxane and TiCl ₄

Thursday, September 3

Session 5 (chairman: Mark Losego)	
09:00 – 09:30	Nari Jeon (invited), <i>Chungnam National University, Republic of Korea</i> Inorganic-Mediated Crosslinking in Hybrid Resists via Sequential Infiltration Synthesis ONLINE
09:30 – 09:45	Silvia Armini, <i>imec, Belgium</i> Area-selective deposition of metal oxides leveraging polymeric materials as non-growth areas
09:45 – 10:00	Eden Elazar, <i>Technion -IIT, Israel</i> Enhancing Composite Materials Performance at Elevated Temperatures Using Atomic Layer Deposition
10:00 – 10:15	Silvia Mirallas García, <i>CIC nanoGUNE BRTA, Spain</i> Sub-surface patterning of polymers with inorganics by area-selective vapor phase infiltration
10:15 – 10:30	Haowen Hu, <i>Instituto de Microelectrónica de Barcelona: Cerdanyola del Valles, Spain</i> Enabling High-Resolution Nanopatterning via Vapor phase infiltration of Perpendicularly oriented PS-b-PLA
10:30 – 10:45	Francesco Bignoli, <i>IMM-CNR, Unit of Agrate Brianza, Italy</i> Operando sequential infiltration synthesis of PLA films and PS-b-PLA lamellae across different temperatures for lithographic applications

PROGRAM

10:45 – 11:15	Coffee break
Session 6 (chairman: John Conley)	
11:15 – 11:45	Rong Chen (invited) , <i>Huazhong University of Science and Technology, China</i> Atomic Layer Infiltration-Enabled Encapsulation Strategies for Stable Stretchable Electronics
11:45 – 12:15	Oksana Yurkevich (invited) , <i>CIC nanoGUNE, Spain</i> Vapor phase infiltration for self-healing of semiconducting materials
12:15 – 12:30	Mari Heikkinen , <i>Aalto University, Finland</i> Atomic/molecular layer deposition of metal ethenetetra thiolate thin films for thermoelectric applications
12:30 – 14:45	Umaid M. Lone , <i>Aalto University, Finland</i> Engineered Inverse Opals for Growth of Nanostructured Ti-Organic Thin Films via Atomic/Molecular Layer Deposition
12:45 – 13:00	Jean-Francois de Marneffe , <i>imec, Belgium</i> High-Fidelity Nanoscale Patterning of MgZnO via Atomic Layer Etching for Advanced Device Integration
13:00 – 13:15	Anil Yadav , <i>Indian Institute of Science, India</i> Low Temperature Atomic Layer Deposition of ZnO for Optoelectronic Applications
13:15 – 14:30	Lunch break
14:30 –	Social program

Friday, September 4

Session 7 (chairman: Michael Nolan)	
09:00 – 09:30	Jan M. Macak (invited) , <i>University of Pardubice, Czech Republic</i> Vapor Phase Infiltration of ZnO nanocrystals into biodegradable fibers for dermatologic applications
09:30 – 10:00	David Bergsman (invited) , <i>University of Washington, USA</i> Overcoming Embrittlement in Vapor Phase Infiltration
10:00 – 10:15	Roman Parkhomenko , <i>CIC nanoGUNE, Spain</i> Vapour-Phase TiO ₂ Modification of PEEK Cages: Subsurface Characterisation and Biological Performance
10:15 – 10:30	Martina Rihova , <i>University of Pardubice, Czech Republic</i> Comparison of ALD and VPI for TiO ₂ deposition on centrifugally spun fibers for photocatalytic applications
10:30 – 10:45	Michele Perego , <i>IMM-CNR, Unit of Agrate Brianza, Italy</i> Alumina Infiltration into Polymer Thin Films: Insights from Operando Spectroscopic Ellipsometry

PROGRAM

10:45 – 11:15	Coffee break
Session 8 (chairman: Rong Chen)	
11:15 – 11:45	Stacey Bent (invited) , <i>Stanford University, USA</i> The Power of Molecular Design in MLD of Hybrid Materials for EUV Lithography
11:45 – 12:15	Maarit Karppinen (invited) , <i>Aalto University, Finland</i> ALD/MLD for Unique Functional Materials
12:15 – 12:30	Olga Partanen , <i>Aalto University, Finland</i> Area-Selective Atomic/Molecular Layer Deposition on Polymer Substrates: Utilizing Intrinsic Surface Chemistry for Low-Temperature Patterning
12:30 – 12:45	Oren Ben Porat , <i>Technion- Israel Institute of Technology, Israel</i> MLD as a Platform to Probe How the Spatial Arrangement of Polyamide Density Governs Membrane Transport
12:45 – 14:00	Lunch break
Session 9 (chairman: Robert Peter)	
14:00 – 14:15	Luis Pinto , <i>Entalpic, France</i> Steerable generative AI for the multi-objective identification of novel ALD precursors ONLINE
14:15 – 14:30	Anthony Tacnet , <i>University Claude Bernard Lyon, France</i> High-quality piezoelectric LiNbO ₃ thin films grown by DLI-CVD enabled by patented fluorinated precursors
14:30 – 15:00	Chang-Yong Nam (invited) , <i>Brookhaven National Laboratory, USA</i> Emerging Reaction Pathways in Vapor-Phase Infiltration in Polymers ONLINE
15:00 – 15:30	Closing ceremony

Area-selective deposition of metal oxides leveraging polymeric materials as non-growth areas

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As critical dimensions in integrated circuits continue to shrink, the alignment of adjacent patterned layers becomes more challenging. In addition, integration schemes and device architectures become very complex both in the lateral and vertical dimensions (high aspect ratio 3D structures). Area-selective deposition (ASD)-driven processes recently gained a lot of attention from the microelectronics industry as a potential solution for the issues associated with top-down pattern formation at the nanoscale. ASD allows circumventing the alignment issue and pattern complexity by exploiting the chemical contrast of the exposed surfaces.

In the first part of this talk, we investigate the selective deposition of TiO₂ enabled by plasma halogenation of amorphous carbon [1] acting as a growth-masking layer. On amorphous carbon, a CF₄ or Cl₂ plasma forms a thin halogenated layer that suppresses the growth of TiO₂, while nucleation remains unaffected on the plasma treated SiO₂. The same halogenation plasmas enable preferential etching of TiO₂ nuclei and selective refreshment of the halogenated surface of amorphous carbon. By embedding the intermediate plasma treatments in the ALD TiO₂ sequence, 8 nm TiO₂ layer could be deposited with a selectivity of 0.998 in the case of the fluorination-based process. The application of the cyclic process on 60 nm half-pitch line pattern resulted in defect-free deposition of TiO₂ at the bottom of the trenches. While exploring the TiO₂ nucleation defects at the limit of detection for conventional element analysis techniques (< 1·10¹⁴ at/cm²), we additionally highlight the value of surface imaging techniques such as AFM for understanding of defect formation mechanisms and accurate assessment of the growth selectivity.

CONTRIBUTED TALK

In the second part of this talk, we study catalytic area-selective etching of a thin C polymeric film from a Ru surface vs. SiO₂ surface to enable area-selective deposition of a metal oxide on Ru. The catalytic decomposition occurs via formation of an O-rich layer of approx. 5 nm at the Ru surface. Overall, this talk highlights the versatility and relevancy of C materials to enable multicolor selectivity schemes.

[1] M. Krishtab, S. Armini, J. Meersschaut, S. De Gendt, R. Ameloot, *ACS Appl Mater Interfaces*, **27** (2021), 32381-32392.

Precursor–Surface Interactions Governing ALD: A DFT Study of Hf Precursors and Co-Reactants on MoS₂

Zsófia Baji,^{1*} Zsófia Bérces¹, Péter Vancsó¹, Dóra Bereczki¹, Robert Grubbs²

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The integration of high- κ dielectric materials with two-dimensional semiconductors is essential for the fabrication of ultrathin transistors, memristive devices, neuromorphic components, and surface-sensitive functional heterostructures. HfO₂ deposition on MoS₂ is crucial for next-generation electronic and sensing applications, however, the chemically inert basal plane of MoS₂ presents a major challenge for atomic layer deposition, resulting in island-like growth, and poor film continuity. Understanding the atomistic mechanisms governing the initial adsorption and reaction steps of ALD precursors on pristine and defective MoS₂ surfaces is therefore critical for achieving controlled thin-film growth. In particular, the role of precursor chemistry, surface defects, and co-reactant interactions determine the quality and functionality of the deposited dielectrics.

In this work, density functional theory (DFT) calculations were employed to investigate the initial steps of hafnium oxide and sulfide growth on MoS₂ with the aim of understanding how precursor and co-reactant chemistry influence the initial stages of ALD growth. The physisorption and chemisorption processes of two hafnium precursors, TEMA₂Hf and TDMA₂Hf, as well as two co-reactants, H₂O and H₂S were examined on pristine MoS₂ and the most common defects.

The calculations show that the precursors do not chemisorb on the pristine MoS₂ basal plane due to the chemically inert nature of the surface, but defect sites offer energetically favourable bonding sites. The physisorption and chemisorption of H₂O and H₂S with pristine and defective MoS₂ were compared. H₂S exhibited stronger bonding in all adsorption geometries, suggesting longer residence times and enhanced chemisorption during ALD processing.

CONTRIBUTED TALK

The results demonstrate that both surface defects and co-reactant chemistry play critical roles in determining nucleation behaviour during the ALD of Hf oxide and sulfide materials on MoS₂.

The presented adsorption trends provide atomistic insight into precursor-specific nucleation pathways relevant to atomic layer processing on two-dimensional materials.

Hybrid Hafniconic Thin Films for Moisture-Responsive Dielectric Applications

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Thin-film humidity sensors frequently suffer from poor long-term stability, hysteresis, swelling, and irreversible degradation under repeated moisture exposure. Among the hybrid organic–inorganic thin film materials, hafnium-based hybrid films remain significantly less explored than their aluminium-based analogues, particularly in sensing applications.

The present work aims at the development of a novel capacitive humidity sensor platform based on hafniconic thin films. Unlike highly water-reactive alucone systems, which are known to undergo severe swelling and degradation under humid conditions, hafniconic provides a more robust hybrid network due to the stronger Hf–O bonding environment, while still retaining sufficient free volume and hydrophilic functionality for reversible humidity-dependent dielectric changes.

Hafniconic films are synthesised by molecular layer deposition using alternating hafnium precursor and ethylene glycol exposures in a low-temperature process compatible with microelectronic device fabrication. As-deposited and thermally treated hafniconic thin films are investigated and modified by ALD infiltration using secondary oxide chemistries to tune dielectric response, water interaction, and structural stability. The sensing devices consist of IDE structures fabricated on the active thin films.

Comprehensive materials characterisation is performed using atomic force microscopy (AFM), X-ray photoelectron spectroscopy (XPS), and electron microscopy to correlate morphology and chemistry with sensor performance.

The Power of Molecular Design in MLD of Hybrid Materials for EUV Lithography

Stacey F. Bent,^{1,*}

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Continued device scaling with the introduction of high numerical aperture (NA) extreme ultraviolet (EUV) lithography will require innovations in photoresist materials. Hybrid inorganic-organic resist materials are promising for EUV lithography because compared to traditional organic resists, they have higher etch resistance, are more impervious to pattern collapse, and are more absorbing of EUV radiation. Molecular layer deposited (MLD) hybrid photoresists offer intrinsic advantages in precise thickness control and chemical homogeneity. However, many MLD resists have poor EUV and electron beam sensitivity, leading to the need to explore new molecular designs. We introduce MLD resists in which we tune the either the metal or the organic linker to develop an efficient solubility switch mechanism. We apply surface spectroscopies to probe the chemical structure, and we investigate the resist patterning via electron beam lithography and flood EUV exposure. We show that by rationally designing the organic linker chemistry, we can create negative tone inorganic-organic hybrid resists with promising patterning properties. These MLD resists achieve down to 12 nm resolution with low line width roughness, while offering the atomic-precision control and chemical homogeneity characteristic of bottom-up synthesis.

Overcoming Embrittlement in Vapor Phase Infiltration

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Vapor phase infiltration (VPI), also known as sequential infiltration synthesis or atomic layer infiltration, is one potential cost-effective strategy for modifying the properties of polymeric materials. In VPI, a polymer is exposed to vapor phase metalorganic reactants which absorb into, diffuse through, and react with the polymer to form a composite. By densifying and crosslinking the material surface, this approach has been shown to increase mechanical strength, improve resistance to etching, and reduce solubility of the host polymer. However, the inclusion of a secondary matrix element, often in the form of metal oxides like alumina, can also serve to embrittle the host polymer. This reduction in toughness can inhibit the polymer's use in areas like membrane separations, where resistance to pressure and the ability to be spiral wound are important considerations. This work will explore how the mechanical embrittlement of polymers due to VPI may be overcome. First, the mechanical properties of aluminum oxide-treated polyethersulfone (PES) membranes will be discussed. Exposure duration and process cycles are shown to control the infiltration depth of reactants and inorganic loading respectively, both of which impact the resulting membrane mechanical properties. Results showed that membranes were more resistant to pressure and less brittle when deeper infiltration depths and lower inorganic loadings were used. These trends were found to agree with theoretical models, such as the rule of mixtures and Gibson-Ashby formulations, which predict that the distribution of alumina would mitigate the loss of ductility. Additionally, the chemical stability of VPI-treated membranes in organic solvents and their separation performance were assessed as a function of alumina infiltration depth, suggesting a tradeoff between chemical and mechanical stability in VPI-modified PES membranes. To overcome this tradeoff, we show how organic reactants may be used instead during VPI, using the in situ growth of metal organic frameworks as a promising example. In doing so, this presentation will showcase the potential use of organic reactants in VPI to expand the library of infiltration processes.

***Operando* sequential infiltration synthesis of PLA films and PS-*b*-PLA lamellae across different temperatures for lithographic applications**

Francesco Bignoli^{1*}, Teresa Elenes-Cervantes², Haowen Hu², Gabriele Seguni¹, Michele Laus³,
Riccardo Chiarcos³, Francesc Perez-Murano², Marta Fernandez-Regulez², Michele Perego¹

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Sequential infiltration synthesis (SIS) is an interesting technique to create hybrid materials or inorganic nanostructures starting from a block copolymer (BCP) template through the exploitation of the different interaction between different polymers and organometallic precursors like trimethylaluminum (TMA) and water for the growth of Al₂O₃ inside the polymer matrix. After the SIS the residual polymer can be removed with a plasma treatment leaving an oxide mask useful for lithographic applications. In this field, poly(styrene)-*block*-poly(lactic acid) (PS-*b*-PLA) forms well-defined microphases with half-pitch as low as 10 nm and the PLA block can be selectively infiltrated by TMA incorporating large amounts of Al₂O₃ with respect to other polymers like polymethylmethacrylate (PMMA) [1].

In this project we explore how the SIS temperature (70°C-110°C) affects the infiltration of TMA in PLA films and lamellae forming PS-*b*-PLA with 10 nm half-pitch through *operando* spectroscopic ellipsometry (SE) and characterization of the Al₂O₃ lamellae obtained upon removal of the polymer phase by O₂ plasma treatment. We observe that the maximum absorption of TMA in the PLA structures is obtained between 70 and 80 °C and that higher temperatures degrade irreversibly the polymer template. Experiments with different numbers of SIS cycles are then performed to optimize the dimensions of the Al₂O₃ lamellae demonstrating that the best performances in terms of combination of high thickness and low line edge/width roughness are obtained after 3 SIS cycles at 70 °C.

CONTRIBUTED TALK

In conclusion, this work provides an overview on the effect of temperature and number of SIS cycles on the infiltration of TMA in PLA based nanostructures paving the way to their possible applications as lithographic hard masks.

[1] M. Perego, A. Motta, K. Rönby, F. T. J. Yap, G. Seguni, C. Wiemer, M. Nolan, *ACS Appl. Polym. Mater.*, **7**(2025), 12707.

Towards Bimetallic Nanowire Arrays with Controlled Compositions Using Block Copolymer Films: The Interplay Between Metal Precursors

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Metallic nanowire arrays are promising components for nanotechnology thanks to their elongated, continuous, and directional structure. *Bimetallic* nanowires offer enhanced performance in catalysis, magnetism, and sensing through synergistic effects between the metals. However, fabricating bimetallic nanowire arrays requires control over their composition and organization. This requirement is addressed by block copolymer films, which serve as scalable templates that self-assemble into periodic arrays with typical periodicities of tens of nanometers. To date, these films have served to create monometallic nanowire arrays via selective impregnation of metal precursors into one phase of the block copolymer film. Subsequent plasma treatment removes the polymer and reduces the precursors to form patterned metallic nanostructures. Control over the composition of bimetallic nanowires requires tuning of the process to the chemistry of each precursor.

Here we demonstrate the use of polystyrene-block-poly(2-vinylpyridine) thin films to fabricate arrays of bimetallic nanowires with controlled compositions of platinum, palladium, or cobalt (**Figure 1**). Nanowire compositions showed nontrivial dependence on the impregnation solution composition, which was strongly influenced by the choice of metal pair. Analysis of the three model metal pairs unraveled different co-impregnation behaviors which correlate with competitive, cooperative, and inhibitive interactions between the metals.[1] These insights enable the fabrication of bimetallic nanowire arrays with compositions tailored to desired properties.

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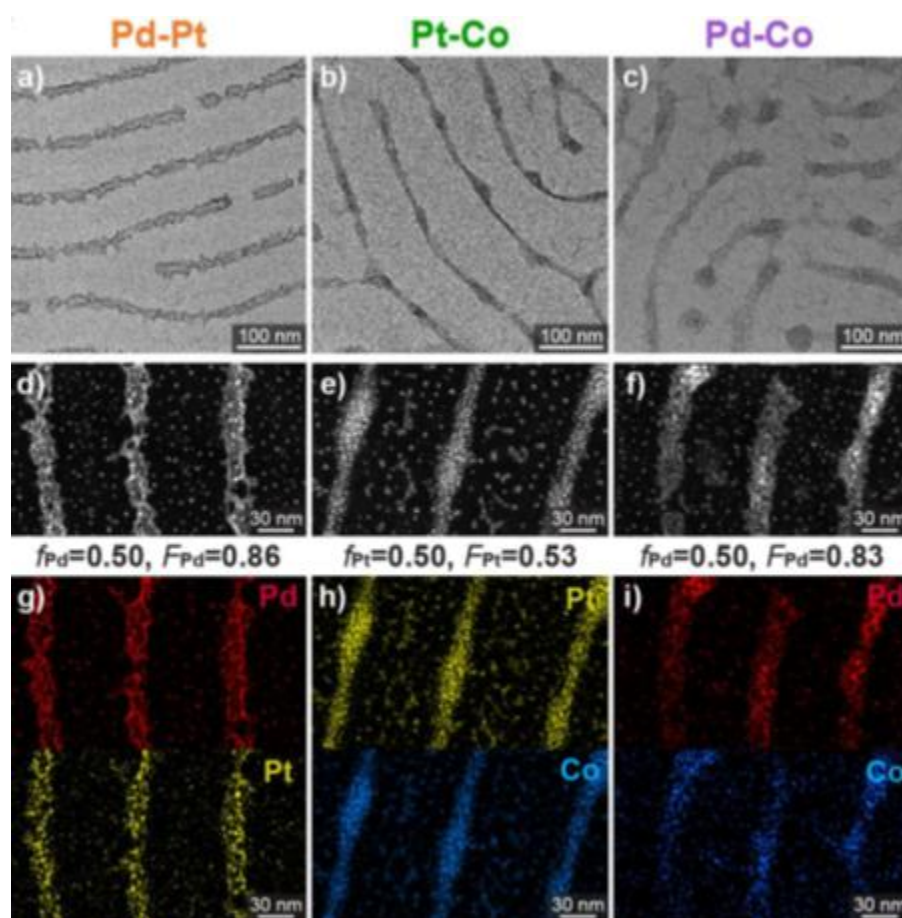


Figure 1. HR-TEM images a)–c), STEM images d)–f), and EDX elemental maps g)–i) of bimetallic NW arrays made using block copolymer templates. The metal fractions in the impregnation solution and in the resulting nanowires are denoted above the elemental maps.

Molecular Layer Deposition of Polyamide Membranes for Selective Water and Ion Transport

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Molecular layer deposition (MLD) enables atomic-scale control over organic and hybrid thin films, yet its use in membrane fabrication remains largely unexplored. Nanofiltration (NF) and reverse osmosis (RO) are central to desalination and water treatment, but the conventional fabrication technique, interfacial polymerization, relies on rapid diffusion-limited reactions that often yield structural heterogeneity and sub-nanometer defects, limiting selectivity [1,2]. Here, we present MLD as a platform for fabricating polyamide (PA) filtration membranes with high uniformity and minimal defects. The optimized 12 nm PA RO membranes achieved a twofold improvement in H₂O/NaCl selectivity relative to commercial desalination membranes. Such defect-free nature of the MLD films also enabled direct probing of intrinsic polyamide transport properties. MLD NF membrane displayed narrow effective pore size distributions and pronounced monovalent-

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divalent ion discrimination in both cation ($\text{Li}^+/\text{Mg}^{2+}$) and anion ($\text{Cl}^-/\text{SO}_4^{2-}$) separations. Overall, this work establishes MLD as versatile platform for fabricating angstrom-precise polyamide membrane, providing new opportunities to design next-generation filtration membranes for advanced water and ion transport.

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Introducing Chemical Vapor Etching (CVE) as Material-Selective Approach for Surgically Precise Tarnish Removal from corroded bronze surfaces

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Bronze cultural heritage relics are highly susceptible to corrosion during environmental exposure. However, selective removal of detrimental corrosion products without altering the underlying metallic substrate remains a major challenge in cultural heritage conservation.

Inspired by the material-selective reactions employed in atomic layer etching (ALE), we developed a chemical vapor etching (CVE) strategy for the controlled removal of corrosion layers from bronze ^[1]. During the treatment, the applied vapors reacted preferentially with the corrosion products while preserving the underlying bronze, as demonstrated by physical and chemical analyses. Depth-resolved chemical characterization confirmed a marked decrease in corrosion-layer thickness after treatment and provided insight into the evolution of the surface composition during etching ^[2]. Although undesired fluorinated species, resulting from the surface chemical reactions, were initially detected at the treated surface, post-processing by mild water-rinsing showed that these transient residues can be effectively removed without compromising the cleaned substrate.

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This study elucidates the chemical selectivity and surface evolution involved in the vapor-phase removal of heterogeneous corrosion layers. More broadly, it demonstrates how concepts derived from atomic layer processing can be transferred to complex, compositionally heterogeneous materials, opening new possibilities for the precise and minimally invasive conservation of metallic (here: bronze) cultural heritage.

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Atomic Layer Infiltration-Enabled Encapsulation Strategies for Stable Stretchable Electronics

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Stretchable electronic devices have garnered surging research interest for applications in flexible displays, wearable electronics, and biomedical healthcare systems. However, the inherent vulnerability of device components to moisture and oxygen severely compromises their long-term operational stability, highlighting the critical demand for high-reliability stretchable encapsulation technologies. Organic encapsulation layers are promising candidates by virtue of their superior softness and mechanical deformability, yet their high free volume structure generally results in unsatisfactory gas and water vapor barrier performance [1]. Herein, we propose an atomic layer infiltration (ALI)-assisted ultraviolet (UV) curing strategy to fabricate organic/inorganic hybrid encapsulation layers with robust barrier endurance under small-strain deformation [2]. A distinctive "inorganic filling–organic crosslinking" synergistic mechanism is unveiled: the infiltrated alumina (Al_2O_3) component not only optimizes barrier characteristics but also facilitates UV-triggered organic crosslinking, raising the bulk crosslinking degree from 17.08% to 74.24%. The optimized hybrid encapsulation structure retains outstanding barrier capability under 1% tensile strain. Benefiting from this protection, the encapsulated wearable sensors achieve stable long-term operation in phosphate-buffered saline (PBS), potassium hydroxide (KOH), and glucose aqueous solutions. Furthermore, by combining block copolymer self-assembly with the ALI technique, an island-patterned composite encapsulation design is developed to accommodate large-strain mechanical deformation. Rigid island domains realize spatial confinement of quantum dots and localized Al_2O_3 deposition, constructing a strain-isolated composite architecture. Combined experimental characterization and finite-element

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simulation verify effective strain partitioning within the hybrid system. This design enables stable photoluminescence output under uniaxial, biaxial, and torsional deformation with strain up to 100%, and exhibits universal compatibility with red, green, and blue quantum dot systems. Collectively, this work establishes versatile ALI-enabled encapsulation strategies to simultaneously address small-strain barrier degradation and large-strain mechanical failure, providing viable technical support for the practical application of high-performance stretchable electronics.

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Enhancing Composite Materials Performance at Elevated Temperatures Using Atomic Layer Deposition

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Composite materials are increasingly used as advanced structural materials in versatile applications, as they offer high specific strength and low weight. However, when the composite materials are exposed to elevated temperatures and oxidative conditions, their performance is limited. Carbon fibers are susceptible to oxidation-induced degradation at temperatures above 400°C, resulting in reduced mechanical integrity. This research investigates the application of atomic layer deposition (ALD) of metal oxides to improve the thermal and oxidation resistance of carbon fiber-polymer composites.

ALD is a vapor-phase technique capable of depositing uniform, conformal thin films with sub-nanometer precision. In this study, we utilize ALD to achieve uniform coatings on carbon fibers, both in bare form and embedded within a polymer matrix, and probe their mechanical performance at elevated temperatures (300°C-600°C). We conformally deposited nanometric Al_2O_3 coatings on the carbon fibers, evident from our scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) characterization. These Al_2O_3 -coated fibers showed superior oxidation resistance, characterized via tensile testing and thermogravimetric analysis (TGA).

This work contributes to the development of thermally resilient composite materials and demonstrates the potential of ALD as a surface engineering tool for composites use at elevated temperatures.

Vapor Phase Infiltration in PS-*b*-PMMA Thin Films: Role of Morphology and Temperature

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Vapor phase infiltration (VPI) enables the incorporation of inorganic materials within organic matrices through the diffusion and reaction of gaseous precursors with specific functional groups. [1]. When applied to self-assembled block copolymers (BCPs) [2], VPI provides a versatile route to produce hybrid organic-inorganic nanostructures and nanopatterned inorganic materials with nanoscale precision, making it highly relevant for advanced nanofabrication and hybrid material design [3, 4]. Despite growing interest, the mechanisms governing infiltration in BCP systems are not yet fully understood. Factors such as polymer morphology, domain size, and interfacial interactions with precursors are expected to play a critical role, but systematic investigations of them remain scarce.

In this work, we investigate the kinetics of Al_2O_3 infiltration into polystyrene-block-poly(methyl methacrylate) (PS-*b*-PMMA) thin films, trimethylaluminum (TMA) and water, focusing on the combined influence of polymer morphology, domain periodicity (Figure 1), and temperature on infiltration behavior (Figure 2). BCP films with different self-assembled morphologies and periodicities were infiltrated under varied conditions to elucidate structure-process relationships governing inorganic compound incorporation.

Our results demonstrate more efficient infiltration in BCP films with smaller periodicities, consistent with their increased interfacial area, which facilitates precursor access to PMMA domains. Additionally, TMA can diffuse through PS domains without reacting, allowing more efficient transport to buried PMMA regions. Temperature also plays a key role in precursor diffusion within polymer matrix. Increasing temperature enhances diffusivity and enables deeper incorporation; however, excessively high temperatures can reduce material uptake, highlighting the need for an optimal balance.

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Overall, this study corroborates previously reported trends in nanostructured polymer systems [5, 6] that are critical for precise control of hybrid atomic layer processing. In addition, it provides a quantitative framework to understand the influence of morphology and temperature, and as well offers valuable guidelines for the design of polymer-templated hybrid for microelectronics, photonics and emerging ALP-enabled technologies.

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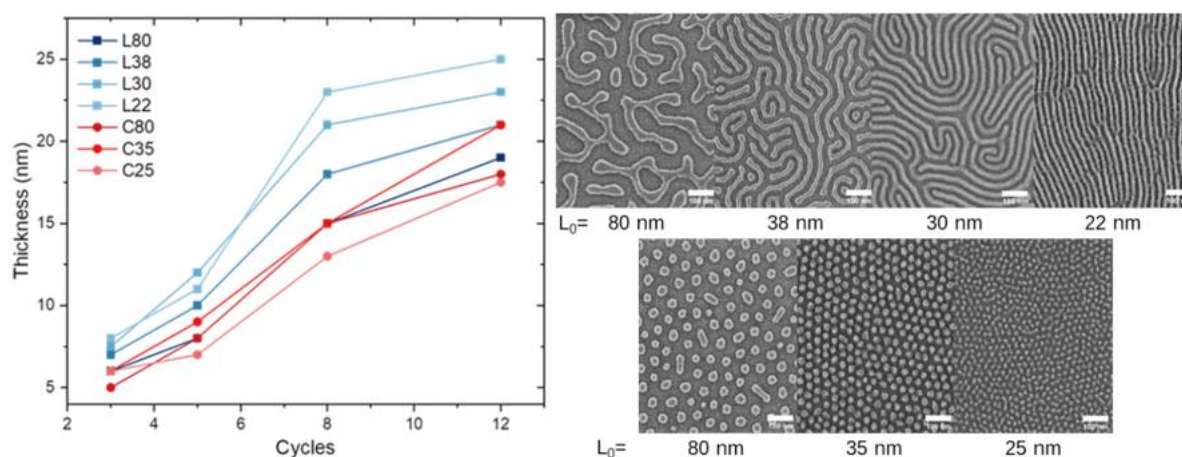
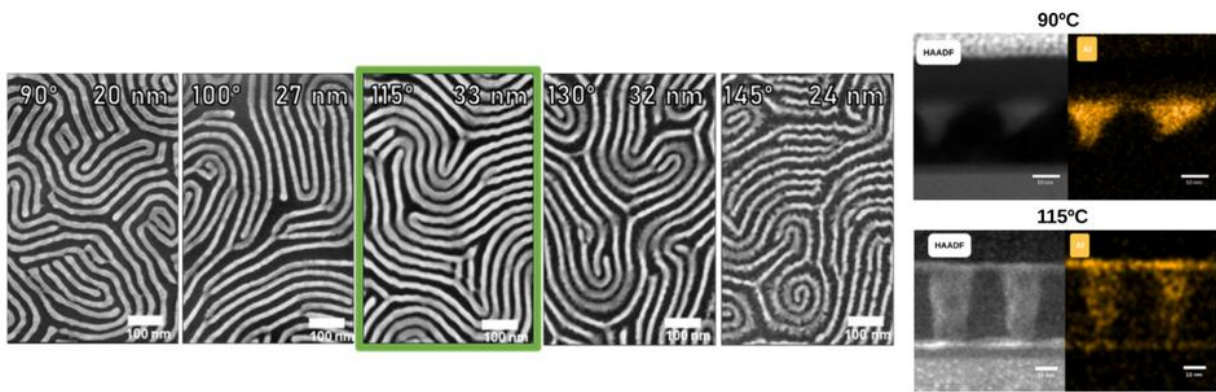


Figure 1 Al_2O_3 VPI at 115°C in PS-*b*-PMMA thin. Left: Infiltration thickness versus VPI cycles for lamellar (L) and cylindrical (C) systems with varying periods. Right: Representative SEM images of lamellar (top) and cylindrical (bottom) .Scale bars: 100 nm.



*Figure 2 Effect of temperature on Al₂O₃ VPI in lamellar PS-*b*-PMMA ($L_0 = 30$ nm) thin films. Left: Top-view SEM images of lamellar morphologies obtained at different infiltration temperatures. Right: Cross-sectional HAADF-STEM images and corresponding Al elemental maps. Scale bars: 100 nm (left) and 10 nm (right).*

Acknowledgements. This work was partially funded by the Swiss National Science Foundation through the project SiDoQu: Nanopatterning and precision polymer doping: towards single-dopant quantum devices (Ref. 100002312), and by SENDESIS (CNS2022-136207), supported by MICIU/AEI/10.13039/501100011033 and by the European Union through NextGenerationEU/PRTR.

Microwave Enhanced Atomic Layer Processing

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Atomic layer processing (ALP), based on cyclic purge-separated self-limiting reactions, enables formation of highly uniform and conformal films with atomic scale thickness control. The low deposition temperatures typical of ALP, however, can allow for incorporation of residual impurities which in turn can lead to non-ideal stoichiometry and sub-optimal film properties. Although elevated temperature *post*-deposition annealing (PDA) can improve film quality, PDA often cannot completely purify the full thickness of a film and the temperatures required can exceed the maximum thermal budget of the substrate or previously formed electronics. To maintain low thermal budget while maximizing film properties, adding annealing or other energy treatments *during* each (or every few) ALP cycle(s) has been shown to help drive / speed reactions and reduce impurity / ligand incorporation. Collectively referred to as energy enhanced (EE) ALD, these techniques are distinct from plasma ALD. Treatments include in-situ rapid thermal annealing (MTA, DADA), flash lamps, plasma exposure, and UV [1,2]. These *in-situ* treatments can remove impurities and defects from the surface of the growing film *before* they become buried, resulting in a more complete densification or purification than PDA. Demonstrated benefits of EE-ALD include improved physical, optical, and electrical properties as well as reduced residual impurities, all at a lower temperature than PDA, and often not achievable by PDA. However, drawbacks of EE-ALD can include added process time, plasma, and/or UV damage.

To try and avoid these drawbacks, we introduce microwave enhanced (MW) ALP [3]. Ex-situ post MW annealing was originally shown to improve dopant activation at reduced temperature while minimizing diffusion, and more recently to improve properties of fully formed ALD films and devices [4]. Here, I describe the development of a MW-ALD system and

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compare MW-ALD of various films with MW-PDA. In-situ MW enhancement may offer the promise of more closely approaching ideal ALD film formation.

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Sequence Matters: Tailoring Al- and Hf-Based Oxide Dielectrics on Monolayer MoS₂

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Two-dimensional (2D) semiconductors, such as transition metal dichalcogenides (TMDs), are promising channel materials for transistor scaling beyond the limitations of silicon technology, due to their superior electrostatic control and retained charge carrier mobilities at atomically thin dimensions. However, their chemically inert van der Waals surfaces hinder nucleation of high-quality dielectrics during conventional atomic layer deposition (ALD), resulting in non-uniform and defective films. This highlights the need for new non-destructive dielectric deposition methods to enable 2D semiconductors integration into next-generation metal-oxide-semiconductor field-effect transistors (MOSFETs).

In this work, we investigate scalable, non-destructive physisorption-assisted ALD processes for depositing combined Al- and Hf-based oxide dielectrics on monolayer MoS₂. We develop low-temperature processes that combine the Al precursor triisobutylaluminum (TIBA), which enables excellent nucleation and uniform coverage on MoS₂ [1], and the Hf precursor tetrakis(dimethylamido)hafnium (TDMAHf) to increase the dielectric constant. Three deposition strategies are compared: (1) ternary films prepared via a supercycle ALD method, in which the precursors' ALD cycles are alternated; (2) bilayer films where alumina is deposited first, followed by hafnia; and (3) the reverse bilayer sequence with hafnia first followed by alumina. Using scanning electron microscopy (SEM), we show that the precursor sequence strongly influences nucleation and growth behaviors on MoS₂. Notably, nuclei morphology and calculated coverages in bilayer films resemble those of the first-deposited material, adopting either AlO_x's mesh-like

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characteristics and higher coverage, or HfO_x 's particle-like characteristics and lower coverage, while the ternary film exhibits a combination of both behaviors. Distinct ternary and bilayer film growths are further confirmed by X-ray photoelectron spectroscopy (XPS). Importantly, all approaches preserve MoS_2 structural integrity, confirmed by Raman spectroscopy. By tuning the deposition approach, we achieve conformal ~ 3 nm dielectric films with complete coverage on MoS_2 . Results on MoS_2 device integration and electrical characterization using the mixed Hf-Al oxide dielectric will be presented.

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Plasma etching for defectivity reduction: the example of TiO₂ area-selective deposition

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Area-selective deposition (ASD) is a cyclic deposition method allowing to simplify processing flows and enable further scaling. However, it might suffer from selectivity loss, appearing typically after a few cycles, leading to the appearance of defects in the non-growth area. One approach to solve this problem is to etch back these defects, reset the surfaces then resume the selective growth until new defects do appear, and so forth.

To better integrate into the ASD sequence, the recess of defects should preferably use dry etching. Contrary to conventional plasma etch, typically requiring high etch rate and anisotropy, the removal of nanometer-sized defects has specific constraints: low etch rate, isotropic, selective to the non-growth surface, and with low roughness.

The present paper describes the challenges of plasma recess of TiO_x outgrowth appearing on a dimethylamino-trimethylsilane (DMA-TMS) passivated SiO₂ surface. The development of the etch process was performed on a 300mm T4 capacitive coupled plasma (CCP) chamber from TEL. The starting point, a TiO₂ line patterning process using BCl₃-CF₄, is found to be way too fast, anisotropic and not selective to SiO₂. Step-by-step tuning of the etch process parameters included plasma pressure, the RF powers applied to the top (source) and bottom (wafer bias) electrodes, and gas mixture (including Ar, CF₄, CH₂F₂, BCl₃, Cl₂, HBr) – see figure 1.

After careful optimization, optimal processing conditions were found, with a TiO₂ etch rate of 0.02 nm/s and a TiO₂/SiO₂ selectivity of 12. These processing conditions were studied in more detail, indicating that the DMA-TMS passivation film is degraded by the plasma, requiring

some restoration before starting a new TiO₂ growth cycle. The removal of Ti from the non-growth, passivated, SiO₂ surface is confirmed by XPS after 50 cycles of TiO₂ deposition (~ 2 nm) and 30s of etch-back, also indicating some residual boron and bromine contamination. Upon fine optimization of the complete [passivation + deposition + etch] supercycles, aiming at minimizing the defectivity on the non-growth surface, the full ASD process was applied to nanopatterns consisting of 45nm half-pitch SiO₂/TiN line-space structures [1]. TEM analysis (see figure 2) indicates that, by having supercycles with more frequent but short plasma recess steps, the defectivity due to TiO_x outgrowth is significantly reduced.

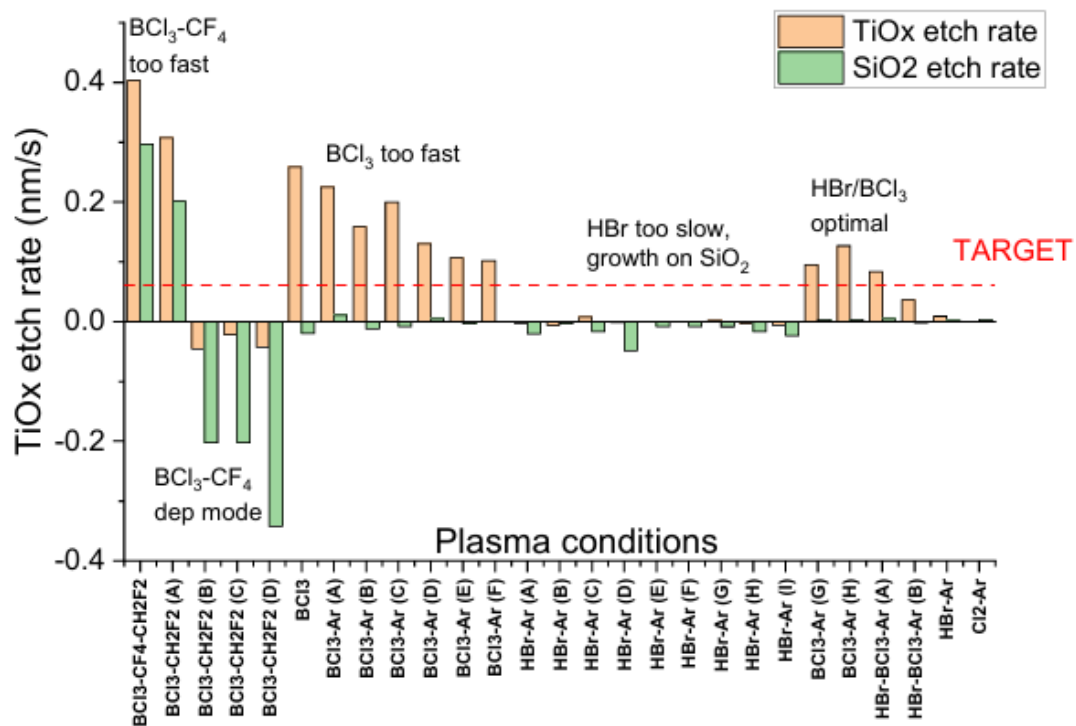


Figure 1: Evolution of the TiO_x and SiO₂ etch rates as a function of different plasma conditions. Negative etch rate indicates deposition rather than etching.

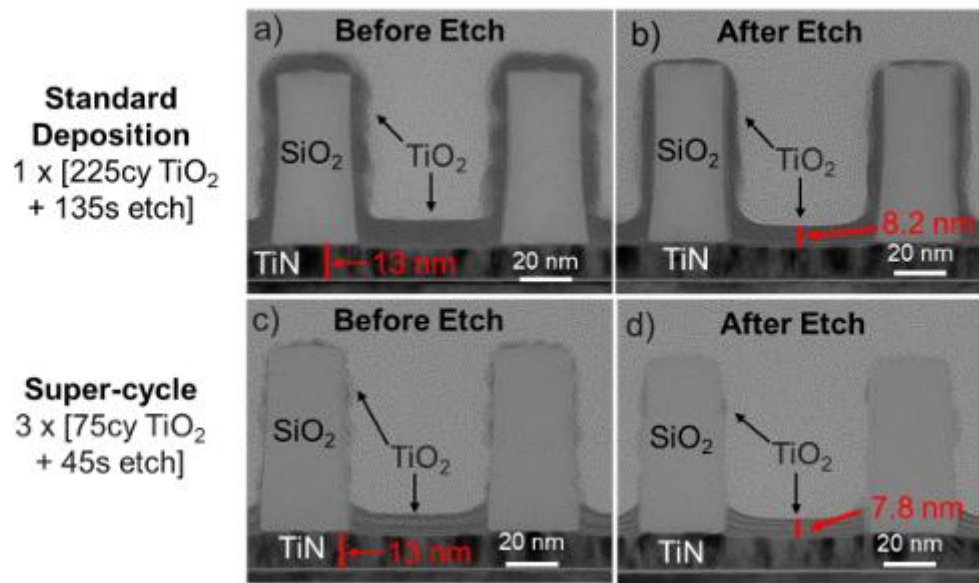


Figure 2: TEM images of “standard” deposition process (top row) versus super-cycle deposition process (middle row) before and after etch steps. Total 225 cycles TiO₂ and 135s etch times were used for each process. Each passivation step was 300 s DMA-TMS at 250 °C.

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High-Fidelity Nanoscale Patterning of MgZnO via Atomic Layer Etching for Advanced Device Integration

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Speaker: Jean-Francois de Marneffe

Magnesium-based oxide semiconductors (OSCs) are promising candidates for emerging memory and electronic devices; however, achieving precise and damage-free patterning of Mg-containing materials remains challenging due to their complex etching chemistry. In this work, we investigate atomic layer etching (ALE) of MgZnO as a representative Mg-based OSC using a controlled cyclic process employing Cl₂ and CH₄ for surface modification and Ar plasma for the removal of reaction by-products. The ALE mechanism involves the simultaneous formation of non-volatile metal chlorides and volatile organometallic species, enabling highly controlled material removal with minimal plasma-induced damage.

Compared to conventional reactive ion etching (RIE), ALE provides superior etch controllability, reduced surface roughness, and improved uniformity of electrical breakdown fields in as-deposited MgZnO films. Patterned etching is demonstrated using SiN/Ru hard masks to define MgZnO line-and-space features with a dense 90 nm pitch. ALE enables well-defined nanoscale features without Mg or Zn redeposition on sidewalls and preserves the stoichiometry of MgZnO within the patterned structures.

Despite these advantages, prolonged ALE exposure leads to profile rounding and gradual degradation of the Ru hard mask. To address this limitation, a pulsed plasma atomic layer etching (PALE) approach is introduced to enhance hard mask stability without compromising etch precision. PALE exhibits highly synergistic and self-limiting behavior, significantly suppresses Ru mask erosion, and improves nanoscale feature fidelity and dimensional control at sub-100 nm pitches.

These results demonstrate that SiN/Ru hard mask engineering combined with PALE represents a robust and scalable strategy for high-fidelity patterning of MgZnO, enabling its integration into advanced device architectures, including transistors, high-density memory, light-emitting diodes, and UV photodetectors.

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Atomic/molecular layer deposition of metal ethenetetrathiolate thin films for thermoelectric applications

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Mechanically flexible thermoelectric materials are needed to tackle energy shortage, storage challenges, and increasing need for heat conversion/efficient cooling for self-powered electronics. There is growing interest in organic TE materials, which consist of earth abundant and non-toxic elements, but the drawback is their low intrinsic electrical conductivity. Coordination polymers of the 1,1,2,2-ethenetetrathiolate (ETT) type have shown promising thermoelectric properties [1], and the Cu- and Ni-based metal-ethenetetrathiolate (M-ETT, M = Cu, Ni) polymers in particular have been reported to exhibit, respectively, p- and n-type electrical conductivity [2]. The combined ALD/MLD technique has been proven to be a successful method for depositing complex metal-organic materials through gas-surface reactions [3]. In this research, we present a novel 3-step ALD/MLD process to deposit these M-ETT thin films [4]. By using an intermediate alkali metal activation step, the otherwise unreactive organic precursor 1,3,4,6-tetrathiapentalene-2,5-dione (TPD) is first converted to an intermediate Li-ETT layer using lithium hexamethyldisilazide (Li-HMDS), followed by a transmetalation step with copper(II) acetylacetonate ($\text{Cu}(\text{acac})_2$) or nickel(II) acetylacetonate ($\text{Ni}(\text{acac})_2$) to allow the end product of Cu-ETT or Ni-ETT. The reaction scheme is given in Figure 1. We recently reported the ALD/MLD like growth for p-type Cu-ETT thin films [4], and here we present – besides the Cu-ETT work – an essentially similar process with nickel to yield n-type Ni-ETT thin films.

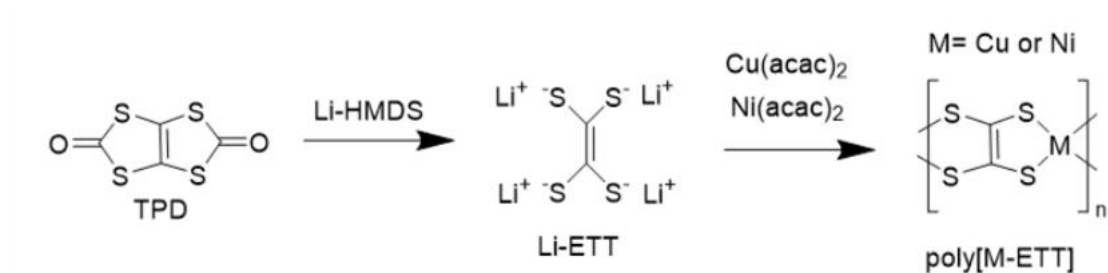


Figure 1. Reaction scheme of M-ETT thin films by ALD/MLD.

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VAPOR PHASE INFILTRATION FOR SWCNT FILLING

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Single-walled carbon nanotubes (SWCNTs), with their hollow core, are highly attractive as nanoscale hosts for a wide variety of guest materials. Encapsulation of materials or molecules inside SWCNTs enables the synthesis of new nanomaterials with enhanced properties by combining the properties of the SWCNTs with those of the filler and/or through the quasi-one-dimensional confinement provided by the SWCNT structure [1]. However, although SWCNTs have been filled with different fillers using various techniques, the control of the filling rate, reproducibility, and the presence of solvent inside the SWCNTs (used as a carrier in classical liquid-phase infiltration and for rinsing molecules adsorbed on the outer walls in vapor-phase methods) still remain open questions [2].

Here, we demonstrate vapor phase infiltration (VPI) as a new route to selectively load SWCNTs through a fully solvent-free process. This technique, derived from atomic layer deposition (ALD), offers the advantage of tunable processing parameters such as temperature, infiltration time, pumping duration, and the number of cycles allowing precise control over material loading and modification [3].

As a proof of concept, we encapsulate the aggregation-induced enhanced emission (AIEE) dye dicyanodistyrylbenzene (BDCS) [4]. The confinement of BDCS inside SWCNTs is anticipated to alter its molecular packing, offering a clear optical indication of both successful encapsulation and molecular organization.

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This strategy positions VPI as a flexible method for designing tailored molecule–nanotube hybrid systems with finely adjustable structure and properties. By enabling controlled modification of SWCNT behavior at the molecular level, it opens new opportunities for advanced applications in nano-optoelectronics, photonic technologies, and photoresponsive devices.

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Enabling High-Resolution Nanopatterning via Vapor phase infiltration of Perpendicularly oriented PS-b-PLA

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Block copolymer (BCP) self-assembly provides a reproducible and scalable route for fabricating nanopatterns^[1]; however, for high-resolution BCP systems, particularly for high- χ (Flory–Huggins parameter) materials, the challenge is to extend beyond perpendicular polymer morphologies to robust transfer into the underlying substrate^[2]. Strong segregation, limited interfacial neutrality windows, and poor etch contrast at small length scales often hinder faithful pattern transfer, restricting integration into microelectronic fabrication processes^[2].

Vapor-phase infiltration (VPI) has emerged as a powerful strategy for reliable pattern transfer, by selectively strengthening one BCP domain and significantly enhancing etch resistance of self-assembled nanostructures^[3]. In this work, we investigate self-assembly and VPI-assisted pattern-transfer of thin films of lamellar PS-b-PLA, a high- χ BCP, aiming at establishing a robust VPI-enabled route toward high-resolution nanopatterning, as schematically illustrated in Figure 1.

Surface energy neutralization using PS-r-PMMA enables obtaining continuous, perpendicular lamellae in PS-b-PLA films under annealing conditions compatible with microelectronic fabrication. The resulting self-assembled patterns exhibit well-defined fingerprint morphologies with lamellar structures having a half-pitch of 10 nm. having a half-pitch of 10 nm.

Building on these optimized self-assembly conditions, VPI is employed to selectively infiltrate the PLA domains, forming an alumina-based hard mask suitable for pattern transfer into silicon. The interplay between the number of infiltration cycles, alumina-etch duration, and silicon-etch conditions is analyzed, revealing a narrow processing window that preserves lamellar fidelity while enabling directional pattern transfer. In particular, optimized conditions yield silicon patterns with etch depths of 20~30 nm, line-edge roughness (3σ) of ~5 nm, and correlation lengths of ~31 nm.

Overall, this work establishes a robust and CMOS-compatible framework that links high- χ BCP self-assembly with vapor-phase infiltration for high-resolution pattern transfer. Overall, this work establishes a robust and CMOS-compatible framework that links high- χ BCP self-assembly with vapor-phase infiltration for high-resolution pattern transfer.

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Solar-Driven Caffeine Degradation Using Porous $\text{Cu}_x\text{O}/\text{Al}_2\text{O}_3/\text{ZnO}$ Heterojunction Films

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The increasing presence of pharmaceutical micropollutants in water has raised the need for effective and sustainable treatment technologies. Solar-driven heterogeneous photocatalysis is a promising approach because it can utilise sunlight to degrade persistent organic pollutants with low energy consumption. In this work, porous $\text{Cu}_x\text{O}/\text{Al}_2\text{O}_3/\text{ZnO}$ heterostructure films were prepared and their photocatalytic activity for caffeine degradation under simulated solar irradiation was investigated.

Porous copper oxide films were fabricated by electrochemical deposition on copper substrates in a 1 M H_3PO_4 electrolyte at 7.5 V and 0.9 A for 10–30 min at room temperature. A thin Al_2O_3 layer was subsequently deposited by atomic layer deposition (ALD), followed by the deposition of a ZnO thin film. The ALD process enabled uniform and conformal coating of the porous Cu_xO surface. The Al_2O_3 interlayer was introduced as a potential passivation layer to improve the stability of the copper-oxide phase, while the copper-oxide/ZnO interface is expected to promote charge separation and suppress electron–hole recombination, as reported for related $\text{ZnO}/\text{Al}_2\text{O}_3/\text{CuO}$ composite systems [1]. Nevertheless, the dominant charge-transfer pathway in the present films depends on the copper oxide phase composition and band alignment [2].

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The photocatalytic performance of the films was evaluated using caffeine as a model pharmaceutical pollutant. The $\text{Cu}_x\text{O}/\text{Al}_2\text{O}_3/\text{ZnO}$ heterostructure showed higher degradation efficiency than bare Cu_xO and ZnO films, demonstrating the beneficial effect of combining the two semiconductors with a thin Al_2O_3 interlayer. Current work is focused on optimising the copper oxide layer by controlling its morphology, porosity, and phase composition in order to further improve photocatalytic performance.

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Atomic Layer Deposition of Hybrid TiO₂-Cu Nanocomposites for Solar Photocatalysis

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Atomic layer deposition (ALD) enables precise control over thin film growth and provides a versatile route for designing hybrid nanocomposite photocatalysts. In this work, TiO₂-Cu nanocomposite thin films were synthesized by ALD, where the amount, size and distribution of Cu nanoparticles were controlled by varying the number of Cu deposition cycles. Structural and chemical analyses confirmed the preservation of the anatase TiO₂ phase together with the formation of metallic Cu nanoparticles uniformly embedded within the oxide matrix. The incorporation of Cu extended light absorption into the visible region due to the localized surface plasmon resonance effect, while photoconductivity measurements indicated enhanced charge transport through electron transfer from Cu nanoparticles to TiO₂. As a result, the TiO₂-Cu nanocomposites exhibited approximately twice the solar-driven photocatalytic activity of pure TiO₂. However, the excess of Cu nanoparticles reduced the photocatalytic performance, showing the importance of precise nanoscale control in ALD. These results demonstrate that ALD is a powerful platform for engineering nanocomposites with optimized architecture and enhanced solar photocatalytic performance.

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Inorganic-Mediated Crosslinking in Hybrid Resists via Sequential Infiltration Synthesis

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The incorporation of inorganic species into polymer matrices has emerged as a key strategy for developing advanced lithographic materials. This presentation examines the modification of poly(methyl methacrylate) resists through sequential infiltration synthesis (SIS), focusing on the fundamental relationship between infiltrated metal oxide domains and the resulting lithographic behavior. By employing diverse precursor sets – including trimethylindium, trimethylgallium, water, and ethylene glycol – we demonstrate the ability to tune the composition and sensitivity of the hybrid network through precursor-specific chemistry. Our investigation, supported by multi-modal spectroscopic and microscopic analyses, reveals that the infiltrated inorganic components serve as distributed nodal sites that facilitate electron-beam induced crosslinking. By correlating the characteristics of these inorganic domains with the resulting negative-tone sensitivity and pattern quality, this work provides practical insights into the design of high-performance hybrid materials. These findings elucidate how atomic-scale inorganic integration influences resist performance, offering a robust framework for the development of next-generation lithographic systems.

ALD/MLD for Unique Functional Materials

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The ALD/MLD technique involving both inorganic and organic precursors allows us to fabricate novel functional hybrid materials not readily accessible through any other fabrication route [1]. By designing the precursors smartly, it is possible to grow even previously unknown crystalline metal-organic structures [2], in which the organic precursor can be further tailored to e.g. enhance electrical conductivity, suppress thermal conductivity, or control light absorption of the hybrid thin-film material as a whole [3]. Moreover, by playing with the ALD and MLD cycle sequences, innovative layer-engineered multi-layer structures can be fabricated [4], to embed variously active or functional organic layers within the inorganic matrix. Similarly to the conventional ALD, both the high-aspect-ratio conformality and the possibility to grow the films in area-selective mode have been demonstrated for the ALD/MLD thin films [5,6]. In this presentation, I will discuss illustrative examples of novel ALD/MLD-enabled hybrid thin-film structures towards luminescence coatings relevant to bioimaging applications [7], UV-switchable magnetic coatings relevant to flexible (spin)electronics [8], and refractive-index tunable coatings relevant to self-cleaning antireflective lenses [9].

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Enhanced Solar-Light Photocatalysis of Cu-Doped ZnO Thin Films on Self-Ordered Porous Anodized Substrates

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The design of highly efficient photocatalytic systems for water purification relies on the development of materials that combine large accessible surface area with strong photoactivity under solar irradiation. In this study, self-ordered porous substrates were fabricated via electrochemical anodization, resulting in well-defined nanoporous architectures with significantly increased surface area compared to planar counterparts. Subsequently, ZnO thin films were deposited using atomic layer deposition (ALD), while Cu doping was introduced in situ to extend the optical response of ZnO from the ultraviolet into the visible region. The structural and morphological characteristics of both the porous substrates and the deposited thin films were examined using scanning electron microscopy (SEM), revealing uniform coating of the high-aspect-ratio porous structures.

A detailed transmission electron microscopy (TEM) analysis combined with energy-dispersive X-ray spectroscopy (EDS) further confirmed the successful incorporation of Cu dopants, demonstrating their homogeneous distribution throughout the entire depth of the ZnO thin film. Photocatalytic performance was evaluated through the degradation of methylene blue in aqueous solution under simulated solar light irradiation.

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The results show that the porous anodized architecture significantly enhances photocatalytic efficiency by increasing the number of active reactions. In addition, Cu incorporation further improves light harvesting and improves photocatalytic activity under simulated solar irradiation. Overall, the combination of self-ordered porous supports and Cu-doped ZnO thin films represents a promising strategy for the development of reusable, high-performance photocatalysts for environmental remediation applications.

Solution- and Vapor-phase Synthetic Approaches to Immobilized Metal-Organic Frameworks (MOFs)

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Metal–organic frameworks (MOFs) are porous materials composed of metal ion clusters interconnected by organic linkers, forming crystalline or amorphous networks with high surface areas, tunable pore structures and chemical functionalities. These characteristics have made MOFs attractive candidates for gas storage and separation, catalysis, sensing, and energy-related applications.[1] While MOFs are traditionally synthesized as powders, their immobilization on solid substrates has become a key step toward these applications.[2] Vapor-phase processing techniques, including atomic and molecular layer deposition (ALD/MLD) have emerged as scalable and sustainable fabrication routes alternative to conventional solution-based synthesis, such as solvothermal growth methods. These methods that utilize precursors from the vapor phase provide superior control over film uniformity and conformality, and facilitate the integration of MOFs in advanced devices, such as membranes, sensors, electrodes, etc.[3] Despite the progress in the direct vapor-phase synthesis of MOFs thin films from vapor-phase precursors, the combination of ALD grown thin films as templates and sacrificial layers in solvothermal methods has been proven a fast and efficient route to the synthesis of surface-mounted highly crystalline MOFs.[3]

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We present our preliminary results toward the growth of MOF thin films on ALD-deposited ZnO using various dicarboxylic acid linkers under solution-phase conditions. In parallel, building on our previous work on the ALD synthesis of metal oxide thin films and the MLD-based stepwise deposition of organic monolayers with terminal carboxylic acid groups,[4] we are planning to develop fully vapor-phase ALD/MLD processes for the fabrication of MOF-coated surfaces for applications in gas adsorption and storage.

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Reaction–Diffusion Modelling of Vapor Phase Infiltration in Block Copolymer Thin Films

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Vapor phase infiltration (VPI) in block copolymer (BCP) thin films enables the selective incorporation of inorganic materials within chemically distinct nanoscale domains, offering a powerful route for fabricating organic–inorganic hybrid nanostructures with controlled chemistry and morphology. However, the coupled roles of precursor diffusion, reaction kinetics, domain geometry, and interfacial transport in governing this selective growth remain insufficiently understood. Here, we develop a 2D time dependent reaction-diffusion model to describe how vapor-phase precursors penetrate, react, and become immobilized within chemically distinct BCP domains. The model links nanoscale domain geometry and polymer chemistry to the resulting spatial distribution of inorganic growth, providing a route to predict and ultimately control selective infiltration in BCP thin films. Using the model we examine how precursor uptake, product distribution, and total mass gain depend on domain size, film thickness, precursor exposure time, and polymer chemistry. The model shows good agreement with the Ren–McGuinness 1D model and with experimental precursor uptake measurements, thereby bridging measurable mass uptake with the underlying spatial evolution of inorganic growth within the polymer template [1]. Overall, this work establishes a modelling platform for deconvoluting transport and reaction effects in VPI of BCPs, advancing predictive control over inorganic growth in polymer nanostructures for nanopatterning and hybrid material design.

POSTER SESSION

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Approaches for Elucidating the Physicochemical Structure of Organic-Inorganic Hybrids Synthesized via Vapor Infiltration of Polymers

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Non-crystalline, organic-inorganic hybrids created via vapor synthesis techniques are challenging to characterize in terms of their physicochemical structure. Without long-range crystallinity, most diffraction-based approaches are not particularly useful. While careful electron microscopy done with methods that do not damage the organic constituents can reveal micro- to nano-scale spatial distributions of elements, these techniques typically fail to provide exact information about bonding chemistry and other short-range structural features, which can be critical to uncovering structure-property relations in these materials. This talk will discuss general approaches we have developed to characterize and deduce the short-range chemical structure in organic-inorganic hybrids created via inorganic vapor phase infiltration (VPI) processes (also known as sequential infiltration synthesis, SIS, and atomic layer infiltration, ALI) applied to organic polymer systems. Our approach is to use a suite of spectroscopic techniques to characterize three specific features: (1) oxidation state of the inorganic, (2) coordination state of the inorganic, and (3) hydration state of the inorganic. A set of deductive processes – applying the constraints of charge state and coordination number – can then be used to develop a model structure and test against additional spectroscopic evidence (like data for the 2nd coordination sphere) or to compare with simulated spectra. While seemingly simple, challenges abound in terms of sensitivity of different elements to different techniques – for example, characterizing coordination state for Al is easily done with NMR but collecting EXAFS data at the Al-edge is challenging at most beamlines because of its low energy and the soft x-ray absorptions in the silicon optics. Hydration state is also often difficult to ascertain and/or differentiate from the metal oxide, but hydrated forms of some inorganics appears to be critical to these hybrid

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structures. Several example systems will be discussed including trimethylaluminum and diethylzinc infiltration into PIM-1 polymers and titanium tetrachloride infiltration into PMMA.

Engineered Inverse Opals for Growth of Nanostructured Ti-Organic Thin Films via Atomic/Molecular Layer Deposition

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Inverse opals consist of a well-ordered three-dimensional (3D) network of voids and can thus be used as template structures with tunable void sizes [1,2]. While the behavior of atomic layer deposition (ALD) precursors in these porous structures has been studied for various applications [3], there are no similar studies for the atomic/molecular layer deposition (ALD/MLD) coatings involving organic precursors. In this work, we investigate the conformality of the ALD/MLD growth of titanium-organic thin films within the three-dimensional (3D) geometry of inverse opals.

We fabricated 3D SiO₂ inverse opal structures with ~213 nm pore diameter via self-assembly method and deposited titanium-hydroquinone thin films through ALD/MLD from titanium(IV) isopropoxide (Ti(OⁱPr)₄) and hydroquinone (HQ) precursors in a hot-wall ALD reactor. We characterized the morphologies of inverse opal structures using scanning electron microscopy (SEM) and evaluated conformality and penetration behavior by cross-sectional SEM image analysis. Our results revealed that the conventional Ti(OⁱPr)₄ / N₂ / HQ / N₂ pulse/purge schemes optimized for planar Si substrates lead to poor void coverage inside the inverse opal structure. The narrowing of voids was more pronounced towards the top layers while the bottom layers were undercoated. To improve conformality, we developed an innovative multi-pulse scheme in which multiple precursor pulses and short purges per cycle are used to ensure that the precursor molecules get numerous opportunities to diffuse deeper inside the porous structure, and the purges help in redistribution and efficient removal of unwanted molecules. This enabled the conformal coating throughout the 3D inverse opal structure.

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Vapor Phase Infiltration of ZnO nanocrystals into biodegradable fibers for dermatologic applications

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Vapor Phase Infiltration (VPI) enables the incorporation of metal oxides into polymer materials [1,2]. Among other applications, it allows the development of active antibacterial polymer-inorganic composites [3,4] and photocatalysts [5]. In this work, VPI was used to infiltrate polyvinyl alcohol or cellulose acetate (CA) fibers with ZnO for the treatment of Acne vulgaris. The fibers were prepared using an innovative centrifugal spinning technique [6] and subsequently subjected to VPI using diethyl zinc and water, leading to the formation of ZnO both within the fibers and on the fiber surfaces [3,4]. Antibacterial testing revealed that both CA and PVA fibers infiltrated with ZnO nanocrystals starting from 32 VPI cycles effectively inhibited the growth of acne-causing bacteria. Moreover, the homogeneous distribution of ZnO nanocrystals within the fibers enabled the immediate release of Zn²⁺ ions while preserving the fibrous structure, in contrast to fibers containing ZnO nanoparticles, which directly blended into the spinning solution [3,4].

The presentation will demonstrate that fibrous carriers combined with active ZnO nanocrystals prepared via VPI represent a highly promising material, showing significant potential for the treatment of Acne vulgaris.

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Growth Temperature-Dependent Microstructural Properties of SnO₂ Thin Films Deposited by ALD and PEALD

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Over the last two decades, tin oxide thin films have attracted significant technological interest due to their advantageous properties. Their wide optical band gap (~3.6 eV), n-type conductivity at room temperature, high chemical stability, excellent optical transparency, and high electron mobility make them suitable for a wide range of applications, including biomedical devices, gas sensors, transparent conducting oxides, and solar cells.

Atomic layer deposition (ALD) is one of the most promising techniques for preparing high quality thin films, as it enables the growth of uniform, conformal layers. SnO₂ thin films were successfully deposited by both thermal ALD using tin tetrachloride (SnCl₄) and water (H₂O), and plasma-enhanced ALD (PEALD) using SnCl₄ and oxygen plasma. In this work, we investigate the influence of various growth temperatures, ranging from 200 °C to 350 °C for thermal ALD and from 150 °C to 350 °C for PEALD, on the film growth rate, as well as on the structural and morphological properties of the deposited films.

A systematic investigation was carried out using scanning electron microscopy (SEM) and transmission electron microscopy (TEM) to characterize the surface morphology, while X-ray diffraction (XRD) was used to determine the crystallographic phase and crystal structure. In addition, X-ray photoelectron spectroscopy (XPS) was performed to analyze the surface chemical composition, and atomic force microscopy (AFM) was used to investigate the surface roughness and topography. Differences between the samples were observed, and the results provide insight into the relationship between the deposition conditions and the resulting microstructural properties of SnO₂ thin films.

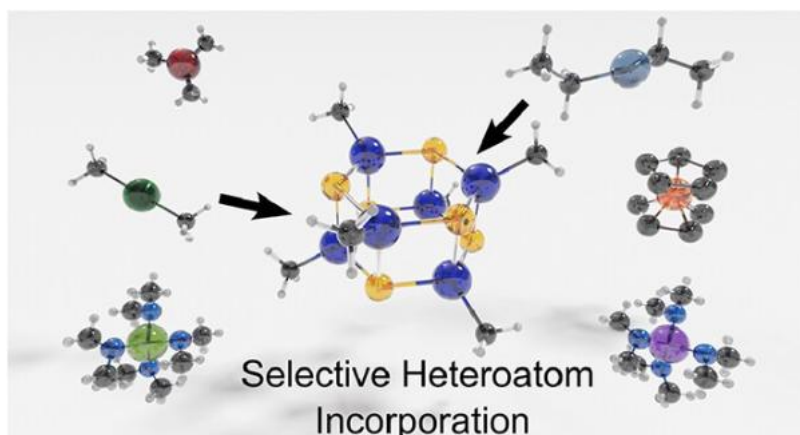
Vapor Deposition of Molecularly Defined Multi-Metal Clusters for Energy Conversion and Photocatalysis

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Magic-sized cluster (MSCs) can be synthesized via a vapor-phase sequential infiltration synthesis (SIS) process into a soft polymeric matrix. The approach offers several advantages, including simplified purification of the resulting clusters (e.g., removal of volatile byproducts), cluster distribution, and a platform for mechanistic investigations into early stage material formation.^{1,2} Gaining mechanistic insight into such a processes may reveal design rules for the synthesis of mixed-metal clusters with controlled composition and connectivity, while also enabling novel pathways to new nanomaterials. We demonstrate that heteroatoms can be incorporated into molecular MSCs via vapor-phase synthesis.³ Exposure of $\text{In}_6\text{S}_6(\text{CH}_3)_6$ MSCs to vapor-phase dimethylcadmium (DMCd) results in Cd incorporation into the cluster structure, the extent of which depends on the process temperature and total DMCd exposure. Elemental analysis and vibrational spectroscopy reveal that Cd^{2+} incorporation is accompanied by the removal of In^{3+} and methyl ligands, indicative of an aliovalent substitution mechanism with charge compensation. Density functional theory (DFT) calculations confirm that both Cd^{2+} incorporation and coordination with the surrounding polymer are thermodynamically favorable. Among eight volatile metal organic ALD precursors experimentally tested, only diethylzinc and DMCd were successfully incorporated, consistent with DFT predictions.



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Sub-surface patterning of polymers with inorganics by area-selective vapor phase infiltration

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The inherent flexibility and processability of polymers make them indispensable for next-generation, flexible electronics, yet their intrinsic electrical properties remain a critical bottleneck for devising various families of electronics [1]. A powerful workaround lies in hybrid materials, which challenge this bottleneck by merging organic and inorganic components to unlock unprecedented functionalities through synergies. Beyond composition, area-selective functionalization is equally critical for the practical construction of electronic devices.

Unlike standard Atomic Layer Deposition (ALD), Vapor Phase Infiltration (VPI) adds a critical dwell phase in the process, allowing extended interaction time in which precursors diffuse into the polymeric matrices and react with functional sites within the bulk material. This creates a hybrid subsurface where the infiltrate and matrix coexist and often show synergies due to chemical or physical interactions [2].

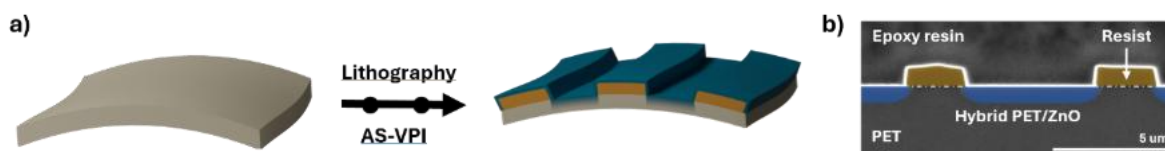


Figure 1. a) Schematic of the workflow of the sample fabrication: bare PET used as substrate in grey and an illustration of area-selectively infiltrated PET (in orange: resist and in blue: ZnO). b) Scanning electron microscopy (SEM) image of a sample with infiltrated area and resist artificially colored.

Here, we demonstrate infiltration of ZnO into a lithographically patterned poly(ethylene terephthalate) (PET) matrix (Figure 1a), locally transferring the pattern into the polymer subsurface (Figure 1b). Following our approach of area-selective VPI (AS-VPI), both the region and the depth of infiltration become controllable, even to the micrometer scale. With linear patterns we demonstrate anisotropic electrical conductivity, showing a difference in electrical resistance of more than seven orders of magnitude between directions parallel and perpendicular to the infiltrated pattern. The benefit of using VPI to embed zinc oxide within the polymeric matrix rather than simply coating the surface is demonstrated by the preservation of electrical resistance after bending and deliberate scratching the sample, as conductive pathways in the subsurface maintain current flow.

This study successfully demonstrates area-selective VPI and its potential application for the first time, representing a foundational step toward device design and fabrication based on selectively embedded inorganic materials within polymers.

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Promoting the synthesis of sustainable aviation fuels (SAFs) over exposed heterointerfaces

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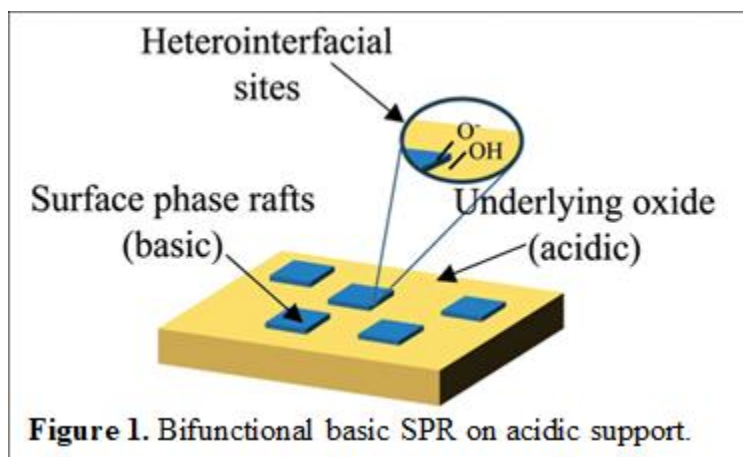
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Sustainable aviation fuels (SAFs) from renewable biomass provide a viable, circular alternative to fossil fuels, but upgrading biomass-derived molecules such as furfural into C₈-C₁₆ hydrocarbons remains challenging.^[1–4] Aldol condensation is strategically positioned to address this by enabling controlled C–C coupling and oxygen removal.^[5–9] However, industrial catalysts often depend on corrosive acids/bases, or expensive noble metals that require extensive purification.^[7, 10–13]

Alternatively, bifunctional acid-base catalysts promote these reactions through cooperative interactions under milder conditions.^[10, 14] In my research, I develop a new concept for engineered acid-base bifunctional catalysts using purely inorganic heterointerfaces. Using Area-Selective Atomic Layer Deposition (AS-ALD), I create thin basic oxide surface phase rafts (SPRs) on acidic support. The exposed heterointerface is expected to provide both acid and base sites in close proximity, inducing bifunctionality (**Figure 1**). This bottom-up strategy ensures high reproducibility and structural stability, overcoming traditional catalyst limitations.



Preliminary results established a reproducible SBA-15 synthesis, providing uniform support for precise ALD validation. An optimized ALD protocol achieved significant internal coating, balancing pore accessibility with practical reaction times. Current work focuses on an area-selective salt masking strategy; optimized deposition parameters developed for silicon wafers will also be applied to SBA-15 to create targeted heterointerfacial sites after ALD and salt removal.

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Mechanisms of Hybrid Atomic Level Processing

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Hybrid Atomic Level Processing (H-ALP) is a variant of atomic level processing in which inorganic and organic species are introduced to produce materials films. It includes *hybrid atomic layer deposition* (ALD) in which a mixed inorganic-organic film is deposited using inorganic and organic precursors, and *sequential infiltration synthesis* (SIS) in which inorganic precursors are infiltrated into a polymer (organic), leading to deposition of the inorganic in the polymer. The relevant chemistry can be studied in detail with first principles simulations.

In this presentation I will discuss the results of density functional theory studies of *hybrid ALD*. The first example is deposition of hybrid materials based on cobalt, using a new Co precursor and a series of para-substituted benzene molecules with -OH and -SH terminations, on SiO₂ [1]. We show that the Co precursor binds to the initial substrate and can eliminate a ligand. The surface bound precursor reacts favourably with the -OH and -SH terminated molecules, eliminating the remaining ligand and yielding oxidized Co bound to the molecule. The half-reactions driving deposition are all favourable. The second example is infiltration of different metal precursors into polystyrene (PS), polylactic acid (PLA) and polymethylmethacrylate (PMMA). Infiltration of Al(CH₃)₃, TMA, into PLA and PMMA shows swelling of the polymer and unravels the preferred reaction sites, while computed vibrational spectra upon TMA infiltration are in agreement with experiment. The swelling of PLA is larger than PMMA, and the swelling persists upon purging; these phenomena are driven by different TMA-polymer interactions and the nature of the polymer side chains [2]. Finally, with Zn(Et)₂ and Zn(DMP)₂ precursors, we find a stark difference in which the infiltration of the Zn precursors is quite low and not particularly favourable, showing that a balance of polymer volume, precursor size and intrinsic reactivity all combine to drive the interaction of precursors in polymers.

INVITED TALK

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Vapour-Phase TiO₂ Modification of PEEK Cages: Subsurface Characterisation and Biological Performance

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Polyetheretherketone (PEEK) is widely used in spinal and orthopaedic implants, but its bioinert surface can limit osseointegration and promote bacterial colonisation. This study investigated vapour phase infiltration (VPI) as a surface modification strategy to introduce TiO₂ into the near-surface region of PEEK. PEEK cages were exposed to the vapors of the precursors (titanium isopropoxide and water) in a custom vapour-phase reactor applying 1,000 VPI cycles at 120, 150, or 180 °C, spanning temperatures below and above the glass-transition temperature of PEEK (143-150 °C). Material characterisation was performed using focused-ion-beam cross-sectional scanning electron microscopy, energy-dispersive X-ray spectroscopy, time-of-flight secondary-ion mass spectrometry (TOF-SIMS), and X-ray diffraction, while preliminary biological performance was assessed using SAOS-2 osteoblast-like cells, *Staphylococcus epidermidis*, *Staphylococcus aureus*, and RAW 264.7 macrophages. Cross-sectional imaging revealed a TiO₂-rich surface layer, with reduced electron-beam-induced delamination following processing at 180 °C compared with 120 °C. Although SEM and EDX did not conclusively demonstrate subsurface infiltration, TOF-SIMS identified an approximately 100 nm TiO₂-rich surface layer together with a gradual Ti/TiO signal transition consistent with an additional 20–30 nm near-surface penetration zone. X-ray diffraction analysis exhibited no crystalline TiO₂, indicating that the inorganic phase remained

CONTRIBUTED TALK

amorphous. In preliminary biological assays, all VPI-treated surfaces increased SAOS-2 metabolic activity and reduced *S. epidermidis*-associated biomass relative to untreated PEEK, with the greatest improvements observed at 180 °C. The 180 °C treatment also reduced *S. aureus* biomass, produced the highest alkaline phosphatase activity on day 6, and decreased macrophage TNF- α release at both 24 and 48 hours. These findings demonstrate that TiO₂ VPI produces an amorphous TiO₂-rich near-surface region with evidence of shallow penetration into PEEK and that processing at 180 °C provides the most favourable overall combination of material characteristics, antibacterial performance, osteoblastic response, and macrophage behaviour. Further quantitative characterisation, mechanical durability testing, and statistically powered biological validation are warranted.

Atomic Layer Deposition for Stabilizing Lithium Metal Interfaces in Next-Generation Lithium Batteries

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Atomic layer deposition (ALD) has become a powerful technique for engineering highly uniform and conformal protective coatings on battery electrode materials. Lithium metal, however, represents a challenging substrate for ALD due to its extreme chemical reactivity, low melting point, and sensitivity toward oxygen and moisture. Understanding interfacial reactions and coating growth mechanisms on lithium is therefore critical for the development of stable artificial interphases for next-generation lithium-based batteries.

In this work, we investigate the deposition process of Al_2O_3 and titanium-based ALD coatings directly on lithium metal surfaces. Al_2O_3 -coatings were deposited using trimethylaluminum and H_2O precursors, while titanium-based coatings were deposited using TiCl_4 and H_2O . The effect of ALD cycle number and precursor chemistry on coating morphology, composition, and interfacial structure was systematically studied.

Operando ambient-pressure X-ray photoelectron spectroscopy was employed to probe the early-stage ALD growth mechanism of Ti-based ALD on lithium metal under realistic deposition conditions. The measurements revealed that the first H_2O pulse rapidly hydroxylates the lithium surface, while subsequent TiCl_4 exposure reacts strongly with lithium species and forms a stable LiCl -rich interphase. Continued ALD cycling leads to the nucleation and growth of a composite TiO_x/LiCl coating with partially reduced titanium species ($\text{Ti}^{3+}/\text{Ti}^{4+}$), indicating complex interfacial redox reactions unique to metallic lithium substrates. Figure 1 illustrates the cross-sectional FIB-SEM view of TiO_x -coated lithium.

POSTER SESSION

This study provides fundamental understanding of ALD nucleation and interphase formation on highly reactive metallic lithium and highlights the potential of ALD for designing tailored protective coatings for advanced energy storage applications.

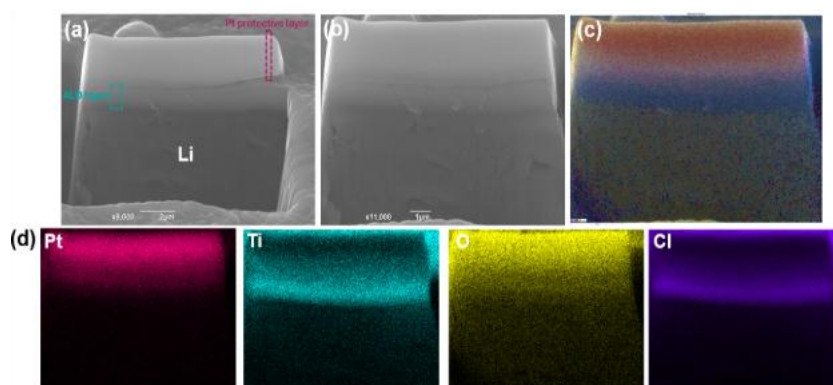


Figure 1. Cross-sectional FIB-SEM images of the TiO_x-coated lithium metal after 10 ALD cycles (a,b). The corresponding EDS analysis (c,d), reproduced from Ref. [1] under CC BY 4.0.

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Area-Selective Atomic/Molecular Layer Deposition on Polymer Substrates: Utilizing Intrinsic Surface Chemistry for Low-Temperature Patterning

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Polymers form a versatile class of materials distinguished by properties such as porosity, mechanical flexibility, and optical transparency, coupled with tunable chemistry and morphology. A broad range of polymer substrates has been explored for surface engineering by atomic layer deposition (ALD), including area-selective depositions (ASD) for bottom-up patterning and vapor phase infiltration (VPI) as a top-down technique. The key limitation, however, is the intrinsically low thermal tolerance (typically below ~150 °C) of most polymers, which significantly narrows the deposition temperature window [1]. Atomic/molecular layer deposition (ALD/MLD), a vapor-phase technique related to ALD, enables low-temperature growth of hybrid inorganic-organic thin films, yielding materials that combine properties such as optical, mechanical, and structural from both chemical precursors. Despite these advantages, area-selective ALD/MLD has been demonstrated only a few times on polymer substrates [2-4]. Here, we investigate area-selective ALD/MLD of Zn-BDT thin films and ZnO:BDT superlattices on a variety of polymer substrates at ultralow deposition temperatures (40–60 °C), using diethylzinc (DEZ), 1,4-benzenedithiol (BDT), and water as the precursors.

Polymer substrates investigated included: different homopolymers (PMMA, PS, PEO, PVP), a block copolymer (BCP) (PS-*b*-PEO), and a DNA origami nanostructure. For characterization we utilized: SEM, AFM, FT-IR, Raman spectroscopy, spectroscopic ellipsometry, XRR, and UV-Vis.

CONTRIBUTED TALK

Our study provides insights into the bonding schemes and fundamentals of ALD/MLD on polymer-based ASD.

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INVITED TALK

Wiley workshop: How to publish in high-impact (factor) journals?

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Always wanted to publish in high-impact (factor) journals? Which journal do you choose from in the ever-increasing number of publishers and their journals? Do you wonder how to write a paper and how to add (more) impact to your paper? Many tips will be given on how to make your submission (even) better! This talk will demystify the publishing process by opening the black-box of submissions, peer-reviewing, and editorial decisions. Please bring all your questions!



Speaker: Dr. Jolke Perelaer, Editor-in-Chief, *Advanced Materials Interfaces*, and Deputy Editor, *Advanced Materials Technologies*, Wiley-VCH, Weinheim, Germany.

INVITED TALK

Jolke Perelaer studied chemistry at Utrecht University in the Netherlands and obtained his Ph.D. also in the Netherlands from the Eindhoven University of Technology in 2009. He continued as a postdoc at the Friedrich-Schiller-University in Jena, Germany, focusing on printed electronics, micro-patterning techniques and nanotechnology. In 2013 he joined the blue & white books department at Wiley-VCH as acquisition editor. In 2016 he joined the Materials Science journals' team as a peer-review editor for a variety of Advanced journals. Currently, he is the Editor in Chief for *Advanced Materials Interfaces* as well as Deputy Editor for *Advanced Materials Technologies*.

Alumina Infiltration into Polymer Thin Films: Insights from Operando Spectroscopic Ellipsometry

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Infiltration of inorganic material from vapor phase into a polymer matrix is a very complex process involving different physico-chemical phenomena like sorption, diffusion and reaction. A clear understanding of the specific impacts of these phenomena on the final amount of inorganic material incorporated into the polymer matrix requires an *operando* analytical tool to monitor the infiltration process in real time. Among the available characterization techniques, spectroscopic ellipsometry represents a valuable option because of the very high time resolution that guarantees the possibility to monitor the different steps of the infiltration process obtaining quantitative and qualitative information about the sorption, diffusion and reaction of the precursor molecules within the polymer matrix. In this work *operando* spectroscopic ellipsometry will be combined with *ex-situ* characterization techniques to investigate infiltration of alumina into different polymers using trimethyl-aluminum (TMA) and water as metal and oxygen precursors, respectively. Poly(methyl methacrylate) (PMMA) [1-4], poly (butyl succinate) (PBS) [4], poly(lactic acid) (PLA) [5], and Poly(ethylene oxide) (PEO) will be considered as polymer templates. Additionally, experimental results will be combined with DFT simulations to explicit TMA infiltration and polymer swelling, providing a consistent picture of TMA interaction with the different polymer matrices [5].

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CONTRIBUTED TALK

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ZnO Thin Films with Embedded Copper Nanoparticles as Plasmonic Photocatalysts for Solar-Driven Wastewater Treatment

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Solar-driven photocatalysis is a promising strategy for sustainable wastewater treatment, yet the limited visible-light response of wide-bandgap semiconductors such as ZnO remains a key challenge. Here, we present ZnO@Cu composite thin films in which metallic copper nanoparticles (Cu NPs, 50-120 nm) are incorporated directly into the ZnO matrix during atomic layer deposition (ALD) growth, via in-situ thermal evaporation of copper(II) acetate. Structural characterization by XRD, XPS, SEM and TEM confirmed that Cu NPs are metallic and homogeneously embedded within the ZnO wurtzite matrix. UV-vis spectroscopy revealed a broad visible-light absorption band attributed to localized surface plasmon resonance (LSPR) in Cu NPs, while Kelvin probe force microscopy demonstrated local surface potential variations near the Cu NPs, indicating electron transfer from ZnO to Cu and the formation of a Schottky-type barrier at the ZnO/Cu interface.

Photocatalytic degradation of methylene blue under simulated solar irradiation showed an approximately threefold enhancement for ZnO@Cu films compared to pristine ZnO.

POSTER SESSION

Scavenger tests identified electron-driven processes as the dominant degradation pathway, consistent with plasmon-induced hot-electron injection from Cu NPs into the ZnO conduction band. This mechanism is directly supported by photoconductivity measurements, which reveal a nearly two-orders-of-magnitude increase in photoinduced carrier generation in ZnO@Cu films relative to bare ZnO. These results establish ALD as an effective route for fabricating plasmonic metal/semiconductor composites, and demonstrate that Cu NPs are a cost-effective alternative to noble metals for enhancing solar photocatalytic activity in ZnO-based systems.

MLD as a Platform to Probe How the Spatial Arrangement of Polyamide Density Governs Membrane Transport

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Reverse osmosis (RO) and nanofiltration (NF) membranes based on polyamide play a central role in global water purification and desalination, but the molecular mechanisms governing water and solute permeation in these membranes remain uncertain. Conventional membranes are typically fabricated via interfacial polymerization (IP), a process that lacks precise control over reaction kinetics and film formation. As a result, the polyamide layer that forms develop a complex and heterogeneous architecture.

In this work, we use molecular layer deposition (MLD) as a platform to investigate how the spatial arrangement of polyamide layers with different structural characteristics influences membrane transport. By constructing multilayer polyamide membranes with controlled layer sequence, we isolate the effect of vertical architecture while maintaining similar overall chemistry and thickness. Our preliminary results indicate that re-ordering these layers leads to different transport performance, highlighting that membrane performance is influenced not only by the overall thickness of the selective layer, but also by the distribution of regions with different densities within it. This approach provides a controlled framework for probing structure-transport relations in polyamide membranes.

These findings highlight the potential of MLD not only as a fabrication method, but also as a tool for studying the fundamental transport mechanisms that govern selective polyamide membranes, and may support the future development of more selective and efficient RO and NF membranes for desalination and water treatment.

Residual Gas Analysis of Atomic Layer Deposition on Powders

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Coating powders with atomic layer deposition allows us to create nanostructured networks in high strength materials [1] or uniformly coated porous electrodes [2]. The progression of half-reactions in the chamber with high surface area can be studied in-situ with residual gas analysis (RGA) carried out with a quadrupole mass spectrometer [3]. In this work, RGA was done with Vision 2000-C system (MKS Instruments) connected to the Beneq TFS 200 fluidized bed ALD reactor. It was revealed that introducing precursors like diethylzinc (DEZ) and heavy water (D_2O) into the spectrometer consecutively as a full ALD cycle significantly influences the measurement. Figures below compare the responses of ethane (reaction by-product) and DEZ when D_2O was introduced to the spectrometer prior (a) and when only diethyl zinc had been directed into the spectrometer multiple cycles in a row (b). It was also shown that it is possible to estimate the saturation point of both half-reactions by repeatably measuring only one.

In-situ RGA allows to estimate the coverage of high surface area substrates. However, the user must be mindful of the interfering processes and should measure by the half-cycle.

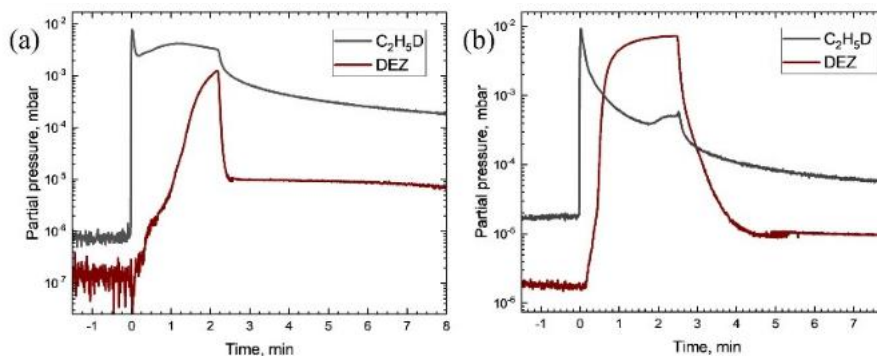


Figure. Ethane and DEZ mass peak lines after D_2O pulse (a); and after D_2O was introduced only into the reaction chamber and not into the spectrometer (b).

CONTRIBUTED TALK

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Steerable generative AI for the multi-objective identification of novel ALD precursors

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Progress within the field of atomic layer processing is frequently hindered by a restricted catalog of precursors capable of meeting the sophisticated demands necessary for precise thin film deposition. Engineering original ALD precursors present significant hurdles in the domain of organometallic chemistry, necessitating a delicate equilibrium between diverse performance goals. Specifically, candidate molecules must maintain room-temperature stability for safe liquid storage and exhibit volatility profiles compatible with standard ALD thermal windows, while ensuring clean substrate reactivity to preclude impurity incorporation. Although chemical intuition and prior expertise have traditionally guided molecular design, there is currently a paradigm shift toward utilizing advanced artificial intelligence to efficiently traverse the vast chemical landscape and expedite the discovery process.

At Entalpic, we have developed a computational framework that employs sophisticated generative AI to identify a diverse array of prospective precursor candidates. Our methodology incorporates a suite of predictive architectures, each optimized for specific ALD-relevant characteristics, to direct generative algorithms toward high-utility molecules via a multi-objective optimization protocol. Initially, a foundation model is trained on open-source datasets, such as those provided by the LeMaterial initiative, to facilitate the generation of organometallic structures. Through adjustable parameters, this system can either assemble complexes using commercially accessible ligand libraries or design entirely novel ligands, while prioritizing the practical synthesizability of the resulting organometallic species.

CONTRIBUTED TALK

Given the pivotal role of ligands in modulating the physicochemical properties of transition metal complexes, we utilize various machine learning architectures—including transformers, graph neural networks, and machine learning interatomic potentials—to yield precise estimates of vapor pressure and other essential properties. These predictive tools offer a critical feedback mechanism to refine our generative models through reinforcement learning techniques. Ultimately, the molecules identified by these specialized generative systems are subjected to rigorous thermodynamic screening to isolate the most viable candidates for subsequent experimental validation and laboratory assessment.

Comparison of ALD and VPI for TiO₂ deposition on centrifugally spun fibers for photocatalytic applications

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Fibrous materials with high porosity and large specific surface area represent highly interesting structures for photocatalytic applications [1,2]. Among various photocatalysts, TiO₂ stands out as a uniquely promising material for fiber-based applications, as it combines photoactivity, chemical stability, non-toxicity, and low cost [3,4]. Centrifugal spinning was used for fiber preparation, as this technology is more economical and environmentally friendly compared to conventional electrospinning. This brings additional benefits in terms of cost and environmental impact [1,2].

In this work, two types of polymeric fibers were employed: polyacrylonitrile (PAN) and poly(vinyl pyrrolidone) (PVP). Vapour Phase Infiltration (VPI) [4] was used to infiltrate TiO₂ into PAN fibers, while TiO₂ was deposited onto PVP fibers via Atomic Layer Deposition (ALD) [5]. Upon thermal post-treatment, PAN fibers were converted into carbon fibers with a TiO₂ nanocrystalline layer, while PVP fibers yielded hollow TiO₂ nanotubes [4,5].

Both materials were tested as photocatalysts for methylene blue degradation under UV light. Carbon fibers with TiO₂ demonstrated increasing photocatalytic performance with higher number of VPI cycles and excellent reuse stability. The best-performing TiO₂ nanotubes showed approximately twice the activity of commercial TiO₂ P25 [4,5].

To the best of our knowledge, this presentation will present the first direct comparison of VPI and ALD approaches for TiO₂ deposition on centrifugally spun fibers. The

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results demonstrate that VPI represents an effective and scalable route for producing stable and highly active carbon-based TiO₂ photocatalysts [4].

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To Infiltrate or Not to Infiltrate? Designing Hybrid Materials with VPI, ALD, and MLD

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Polymers are central structural and functional materials, yet their performance is often limited by UV degradation, hydrolysis, and poor control over interfacial structure. This talk will discuss vapor-phase strategies for controlling both inorganic and organic material growth within and on polymer substrates, using atomic layer deposition (ALD), vapor phase infiltration (VPI), and molecular layer deposition (MLD). In the inorganic case, we show that sequential VPI and ALD enable robust ZnO–polymer hybrid structures on poly(lactic acid) (PLA), where VPI creates subsurface and surface nucleation sites that promote conformal ZnO growth during ALD. While VPI or ALD alone provides limited protection, their combination yields polycrystalline ZnO coatings that reduce polymer photodegradation by more than two orders of magnitude, while preserving transparency in the visible range. Treated 3D-printed PLA structures remain intact and flexible after extended UV exposure, highlighting the potential of this approach for extending polymer lifetimes and reducing plastic waste in outdoor environments.

Complementing inorganic hybridization, we examine all-organic VPI and MLD as routes to chemically resilient polymers. Aromatic polyamide, polyurea, and polyimine chemistries were investigated to understand how precursor chemistry, polymer functionality, diffusion, and reaction kinetics govern organic material growth inside polymer matrices. In nucleophile-rich poly(vinyl alcohol), organic VPI enables covalent modification and cross-linking, with reaction–diffusion analysis distinguishing diffusion-limited polyamide growth from reaction-limited polyurea growth. Unlike hydrolysis-sensitive inorganic alumina modification, organic vapor-phase modification preserves polymer integrity even under strongly alkaline conditions, demonstrating a pathway toward water- and solvent-resilient polymer

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materials. Moreover, controlled organic growth on polymers is the basis for our work on MLD-based desalination membranes.

Together, these studies establish vapor-phase growth as a versatile platform for molecularly engineering polymers and polymer interfaces. By controlling where and how organic and inorganic materials grow, these methods enable durable, functional polymer systems for environmental applications.

Sequential Infiltration Synthesis for Organized Nanostructure Fabrication

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Sequential infiltration synthesis (SIS) is a three-dimensional growth process derived from atomic layer deposition (ALD) on polymers. SIS permits to grow inorganic materials into polymeric films. SIS into self-assembled block copolymers (BCP) offers the possibility to fabricate inorganic nanostructures starting from nanostructured organic templates. The fine-tuning of the dimensions of the resulting nanostructures can be achieved by proper selection of the SIS process conditions. In particular, the sequential reaction steps of the SIS process allow tuning the dimensions of the nanostructured material adjusting the number of SIS cycles. This capability to achieve a fine tuning of the dimensions of the resulting inorganic nanostructures is fundamental to make this technology suitable for the different target applications. At the same time, this step-by-step growth of the inorganic nanostructure allows us to obtain information about the progressive mass uptake of the inorganic component into the polymer matrix and to delve into the growth mechanism. In this work, Al₂O₃ dot, antidot, [1] or lamellae, [2] or rings [3] arrays were synthesized by infiltration of trimethylaluminum and water precursors into out of plane cylinder or lamellae forming poly(styrene-*block*-methyl methacrylate) (PS-*b*-PMMA) BCP thin films. Collected data provided information about the mechanism governing the effective incorporation of Al₂O₃ into the PMMA component of the BCP thin films. Overall, this study collects exhaustively the infiltration behaviour in different PS-*b*-PMMA nanostructures and consequently improves the application of SIS generated masks from PS-*b*-PMMA in industrial lithographic processes.

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Atomic and molecular layer deposition engineered ceramic membranes for nanofiltration and solvent-resistant nanofiltration

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Sustainable and circular-economy practices are increasingly important for reducing carbon emissions in industrial manufacturing. Liquid purification, which entails separating organic solutes and solvents from process streams in the pharmaceutical, textile, agricultural, and petrochemical sectors, exemplifies this need. These industries demonstrate a significant demand for lower-energy alternatives to conventional, energy-intensive methods such as distillation. Ceramic membranes are recognized for their structural versatility, operational simplicity, and effectiveness in liquid separation. Their high thermal and chemical stability make them suitable for industrial-scale applications. Furthermore, ceramic membranes offer extensive surface areas with abundant active sites for surface-engineering. However, the development of nanofiltration (NF) and solvent-resistant nanofiltration (SRNF) membranes is limited by challenges inherent to current state-of-the-art techniques, particularly the sol-gel process such as non-uniformity, variability in pore size, pore-size distribution, and process parameters.

This study provides an overview of NF and SRNF membranes fabricated by atomic and molecular layer deposition (ALD and MLD), with references to the authors' recent work [1-4]. The analysis evaluates the performance of these membranes and assesses the suitability of ALD and MLD techniques for achieving precise control over pore size, pore-size distribution, surface hydrophobicity (effect of air/nitrogen annealing), and physicochemical

properties (such as layer thickness, composition, and layer-solvent interactions). NF membranes produced by MLD exhibit pore sizes (radii) around $\sim 0.8 \pm 0.1$ nm and demineralized-water permeance of 13 ± 1 L·m⁻²·hr⁻¹·bar⁻¹ with >90% rejection of polyethylene glycol (PEG) molecules with a molecular weight of 380 ± 6 Dalton. Similarly, SRNF membranes fabricated by these methods with surface hydrophobicity >90° and pore diameters <2 nm achieve over 90% rejection of PEG molecules >390 Dalton and n-hexane permeance >10 L·m⁻²·hr⁻¹·bar⁻¹. Collectively, these findings demonstrate the effectiveness of ALD and MLD in tuning selectivity and permeance, and underscore their efficiency for membrane engineering, size-selective separation, and large-scale industrial applications with atomic-level precision.

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Plasma-Assisted ALD/MLD of SiOTiNC Hybrid Ultrathin Films from Cyclic Tetrasiloxane and TiCl_4

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Siloxane-based polymers are known for properties such as low elastic moduli, high mechanical flexibility, hydrophobicity, and good chemical and thermal stability. Many of these characteristics are closely related to the highly flexible Si–O–Si backbone, which provides a high degree of molecular mobility and, consequently, a low glass-transition temperature. Polysiloxane thin films synthesized via initiated chemical vapor deposition (iCVD) from cyclic 1,3,5-trivinyl-1,3,5 - trimethylcyclotrisiloxane (V_3D_3) and 1,3,5,7 - tetravinyl - 1,3,5,7 tetramethylcyclotetrasiloxane (V_4D_4) have been shown to exhibit low dielectric constants, low surface energy, low leakage current densities at nanometre-scale thicknesses, and high optical transparency, highlighting their potential as gas-phase precursors for functional ultrathin coatings [1]. Incorporation of titanium has been shown to expand the range of functional properties and potential technological applications of siloxane-derived and SiOC-based materials. Ti-containing siloxane hybrids and Ti–Si mixed oxides exhibit composition-dependent refractive indices, optical band gaps, dielectric properties, and charge-transport behavior [2]. Moreover, Ti-modified SiOC ceramics show altered high-temperature phase

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evolution and, at suitable Ti contents, improved resistance to crystallization and oxidation, as well as enhanced thermal stability [3]. Although solution-based methods are traditionally used to prepare organosilicon-based organic–inorganic hybrid coatings, their application can be limited by solvent contamination, wetting and edge effects, and difficulties in achieving uniform coverage on complex or high-aspect-ratio substrates. Atomic layer deposition and molecular layer deposition (ALD/MLD) offer a solvent-free alternative, enabling the deposition of high-quality conformal hybrid thin films with precise control over thickness and composition at the nanometer scale [4].

In this work, we introduce a plasma-assisted sequential ALD/MLD methodology for the vapor-to-solid synthesis of hybrid SiOTiNC ultrathin films using 2,4,6,8-tetramethyl-2,4,6,8-tetravinylcyclotetrasiloxane (V_4D_4) and $TiCl_4$ as precursors, with N_2 / NH_3 plasma. Film growth was monitored *in situ* by quartz crystal microbalance (QCM) measurements, while the composition, chemical bonding, optical properties, surface morphology, nanomechanical properties, and elemental depth profiles of the resulting films were investigated using XPS, ATR-FTIR, UV–Vis, AFM, SIMS, and SEM, respectively. Variation of the V_4D_4 pulse duration enabled tuning of the film composition, including the Ti/Si ratio and the carbon and nitrogen contents. Upon annealing the deposited films in an Ar atmosphere, nitrogen was largely depleted by approximately 600–700 °C, while further heating between 1000 and 1200 °C promoted conversion toward Ti–Si–O–C ceramic-like structures, with a minor TiC contribution. The developed process enables vapor-phase deposition of Ti-containing, siloxane-derived ultrathin films with tunable preceramic composition and potential for conversion by pyrolysis into ceramic-like coatings for high-temperature applications.

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High-quality piezoelectric LiNbO₃ thin films grown by DLI-CVD enabled by patented fluorinated precursors

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Reaching the full potential of 5th generation mobile telecommunications (5G) and component miniaturization requires not only the development of advanced piezoelectric thin films for high-frequency RF acoustic filters but also their significant downsizing. However, developing such thin piezoelectric layers presents challenges due to the need to achieve extreme miniaturization while maintaining strict control over homogeneity [1].

Piezoelectric thin films made from alkali niobates (LiNbO₃/KNbO₃) are typically fabricated from single-crystal wafers via bonding, ion slicing, or polishing processes. These methods, however, face limitations, particularly with imperfect thickness control. To address these challenges, various techniques have been explored, including capillary liquid epitaxy, RF magnetron sputtering, etc [2].

Despite these advances, very few alkali precursors are known for vapor-phase processes such as MOCVD or atomic layer deposition (ALD) [3][4]. To address these issues, we have concentrated our efforts on synthesizing novel alkali precursors optimized for the growth of alkali niobate thin films using DLI-MOCVD. These innovative precursors are designed to overcome current limitations, enabling scalable and precisely controlled deposition processes. To tackle these challenges, we decided to study fluorinated aminoalkoxides due to their thermal properties, which are highly compatible with DLI-CVD deposition processes. The presence of fluorinated groups enhances volatility by introducing negative charges that promote repulsive intermolecular interactions. Through a controlled synthesis, we successfully developed a series of lithium, potassium and sodium precursors with high yields

and excellent purity. These precursors were employed in DLI-MOCVD processes to deposit MNbO_3 (M = Li or K) thin films with a precisely controlled thickness of 150 nm. Furthermore, we optimized the deposition parameters to achieve thin films with controlled crystalline orientation and without parasitic phases. The optimization of these parameters allowed us to obtain films exhibiting a single, well-controlled crystalline orientation.

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Hybrid metallosaccharide films for protecting wood from environmental damage

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Wooden cultural relics are highly vulnerable to water-induced degradation.^[1] Their cellulose-based structure allows microbial growth^[2], causes chemical instability and eventually leads to dimensional deformation. Developing non-invasive and durable protection strategies for wood remains an ongoing challenge.

In our work, we fabricated a Ti-based metallosaccharide hybrid nanofilm via molecular layer deposition (MLD) to protect wood from environmental harm. XPS analysis (Figure 1a) reveals the formation of Ti-O-C bonds, confirming successful construction of an organic-inorganic hybrid network. The coating exhibits reduced moisture diffusion, enhanced water repellency, and improved physicochemical stability under both acidic and alkaline environments.

When deposited on birch wood, the hybrid film significantly improves the wood's dimensional stability during wet-dry aging, as evidenced by reduced deformation (Figure 1b). In addition, the water repellence over extended time and the mechanical properties (Figure 1c, d) progressively improved with increasing Ti-ribose film thickness.

Overall, this study demonstrates that MLD-derived metallosaccharide films provide a conformal, non-invasive, and sustainable strategy for enhancing durability, making them highly attractive for applications in wooden cultural heritage conservation.

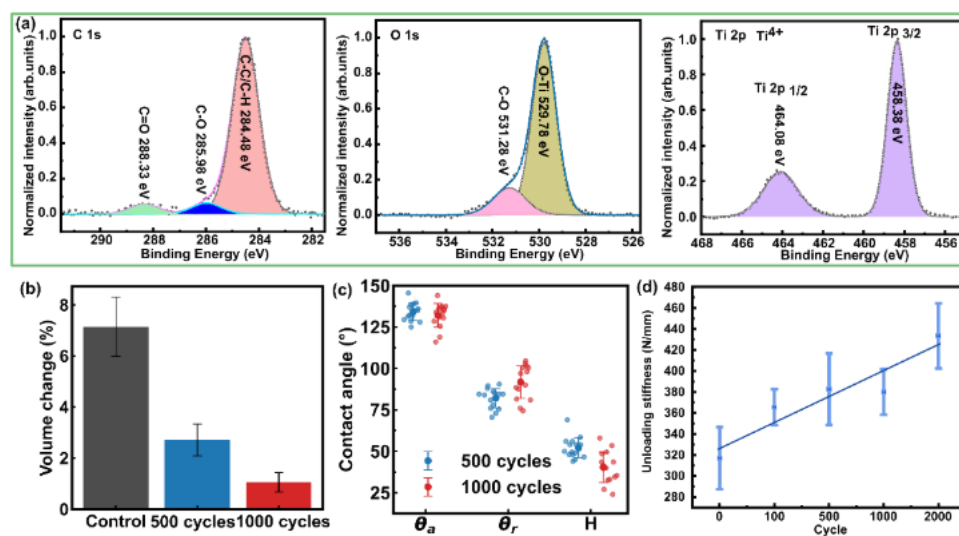


Figure 1 (a) XPS spectra of C 1s, O 1s and Ti 2p of Ti-ribose hybrid film; (b) Volumetric change of birch before and after wet-dry aging cycles; (c) Dynamic (advancing and receding) contact angles of birch after five wet-dry aging cycle; (d) Unloading stiffness of birch with different Ti-ribose deposition cycles.

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Low Temperature Atomic Layer Deposition of ZnO for Optoelectronic Applications

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This work demonstrates the ultra-low-temperature atomic layer deposition (ALD) of ZnO thin films at 50 °C and 70 °C using a 1 M diethylzinc (DEZ) solution in hexane and water as precursors. This was achieved in a custom-built ALD chamber with precise control over the process parameters. Despite the ultra-low deposition temperatures, the resulting ZnO films demonstrated excellent uniformity. This approach not only solves the problem of substrate compatibility by enabling ultra-low-temperature growth but also demonstrates the use of solvent-diluted pure precursors. Figure 1 represents the X-ray diffraction (XRD) patterns of the as-deposited ZnO thin films on quartz substrates. Figure 1a illustrates the structural evolution of the films deposited at 50 °C as the number of ALD cycles increased from 50 to 250. As the ALD deposition cycles increased to 100, distinct diffraction peaks corresponding to (100), (002), and (101) planes emerged. When the deposition temperature increased from 50 °C to 70 °C, the (002) peak became more intense and sharper, indicating improved crystallinity as shown in Figure 1b.

To evaluate the electronic properties of ZnO thin films deposited at ultra-low temperatures, we integrated them as the active layer in field-effect transistors (FETs), labelled as ZnO-50 (for deposition temperature 50 °C) and ZnO-70 (for deposition temperature 70 °C). The fabricated devices demonstrated exceptional electrical characteristics, shown in Figure 2, exhibiting an I_{on}/I_{off} ratio exceeding 10^8 with the saturation mobility of $0.085 \text{ cm}^2/\text{V}\cdot\text{s}$. These results clearly confirm the applicability of solution-based precursors for ultra-low-temperature ALD depositions in electronic device applications.

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Figure 1: X-ray diffraction spectra of ZnO thin films as a function of the number of ALD cycles deposited at a) 50 °C and b) 70 °C.

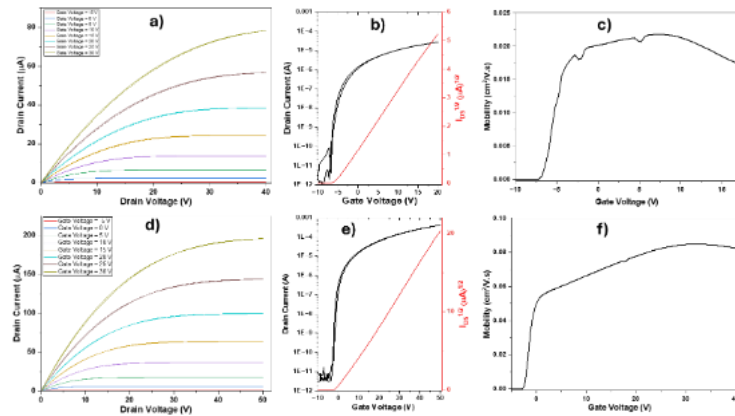
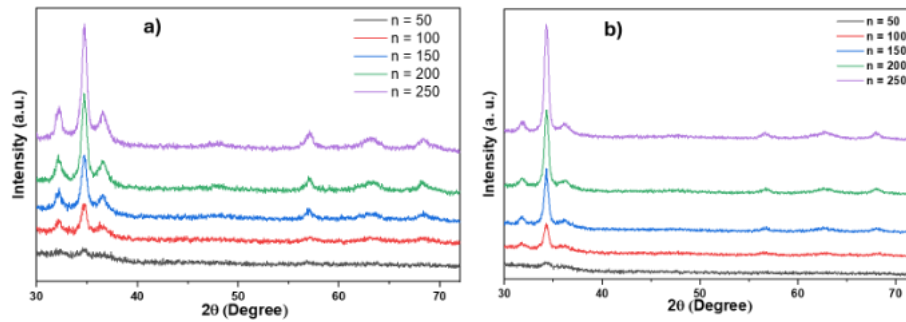


Figure 2: Electrical characteristics of fabricated FETs. (a-c) characteristics of ZnO-50 device, with a) output characteristics, b) transfer characteristics in saturation regime, and c) mobility as a function of gate voltage. (d-f) corresponding characteristics for the ZnO-70 device, illustrating d) output characteristics, e) transfer characteristics in the saturation regime, and e) saturation mobility as a function of gate voltage.

Emerging Reaction Pathways in Vapor-Phase Infiltration in Polymers

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Vapor-phase infiltration (VPI) enables a wide range of functional organic-inorganic hybrid materials, and its mechanisms have been extensively studied. While key fundamentals are established, recent studies point to additional pathways governing precursor-polymer interactions. In this talk, I will highlight two such cases in poly(methyl methacrylate) (PMMA), a prototypical VPI system. First, in AlO_x -primed ZnO infiltration using diethylzinc (DEZ), alumina priming electronically activates carbonyl groups, enabling their direct reaction with DEZ—a weak Lewis acid whose direct interaction with PMMA carbonyls is otherwise ineffective—beyond conventional hydroxyl-mediated pathways, leading to sustained uptake and deeper penetration. Second, tetrakis(dimethylamido)hafnium (TDMAHf) exhibits temperature-dependent behavior, forming reversible adducts at moderate temperatures and transitioning to covalent bonding at elevated temperatures via ligand dissociation and polymer modification through dealkylation. Advanced characterization techniques, including infrared spectroscopy, synchrotron X-ray absorption spectroscopy, and electron microscopy, combined with first-principles calculations, provide direct evidence of these processes, revealing a broader and still-evolving mechanistic landscape for VPI.

Vapor phase infiltration for self-healing of semiconducting materials

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Self-healing is an increasingly important functionality for modern technological systems, particularly in the context of flexible electronics and sustainable device design. A widely explored strategy for self-healing conductive materials relies on liquid metals that can flow into damaged regions, reconnecting conductive pathways. However, a different approach is needed to achieve self-healing in inorganic semiconducting materials.

We present an alternative concept based on vapor phase infiltration (VPI), enabling self-healing in solid-state polymer-inorganic hybrid materials. VPI is typically employed to modify polymer properties, but it can also be used to grow inorganics within the polymer bulk. In that case, the polymer serves both as a flexible substrate and as a reservoir for embedded inorganic clusters beneath an oxide coating. If sufficient mobility of these clusters is achieved, they can migrate toward defects in the coating, enabling autonomous healing.

We focused our studies on self-healing hybrid systems composed of ParyleneC or PVC and infiltrated with ZnO or In₂O₃. Upon mechanical or focused ion beam-induced damage, the systems exhibit rapid defect healing upon exposure to ambient conditions. Electron microscopy and spectroscopy analyses reveal that healing occurs through the migration and agglomeration of embedded nanoparticles (NPs) toward the damaged region, resulting in partial restoration of both morphology and electrical functionality. A key finding is the critical role of chlorine, originating from the polymer matrix or precursor chemistry, in enabling nanoparticle mobility. It leads to reversible chemical transformations at

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the defect site, and moreover, weakens interaction between NPs and the polymer. The infiltrated systems and their healing behavior were investigated through a combination of advanced characterization methods, including TOF-SIMS combined with SEM, 3D reconstruction, and in situ electrical measurements inside an electron microscope. Employing VPI enables us to tune the surface chemistry of nanoparticles grown within a polymer, such that the cluster migration and consequently, healing is possible. The resulting self-healing materials, which enhance structural resilience by autonomously repairing damage, directly support emerging EU regulations mandating that consumer products be designed for longer lifespans to reduce waste and improve resource efficiency.