ALD Applications
Room Tamna Hall A - Session AA3-WeA
Emerging Applications

Moderators: Bong Jin Kuh, Samsung Electronics, **Markku Leskelä**, University of Helsinki, Finland

4:00pm **AA3-WeA-11 Atomic Layer Deposition for Self-Healing Stone Cultural Heritage Preservation**, *Ancy Mini Vibin Lal Nayakom Mini, Gabriele Botta, Mato Knez, **Aranzazu Sierra Fernández,*** CIC nanoGUNE, Spain

The preservation of stone cultural heritage (CH) materials faces growing challenges due to environmental stressors exacerbated by climate change. Fluctuating humidity, temperature variations, and air pollutants accelerate ageing and erosion, compromising the structural integrity of historical materials. To address these issues, we develop advanced self-healing coatings designed to repair microdamage and enhance the durability of stone substrates. Inspired by the autonomous repair mechanisms observed in ancient Roman concrete, our research seeks to translate this phenomenon into protective coatings. Using Atomic Layer Deposition (ALD), we create structured nanofilms capable of mimicking self-healing properties, significantly improving the long-term preservation of stone substrates.

A key aspect of this research is the functionalization of the stone surface to optimize coating deposition, ensure homogeneity, and improve chemical adhesion. Refining pre-treatment methodologies enhances the chemical affinity and uniformity of the coatings, maximizing their stability and self-healing efficiency. The ALD process provides nanoscale metal oxide films, which, upon exposure to environmental humidity and atmospheric CO_2, initiate mineral nucleation and growth. This controlled mineralization autonomously seals microcracks before they propagate, reinforcing the mechanical stability and durability of treated stone substrates.

To assess self-healing performance, we employ nano- and microindentation techniques to monitor changes in hardness and elastic modulus across different scales, providing quantitative insights into mechanical recovery. Additionally, high-resolution Focused Ion Beam Scanning Electron Microscopy (FIB-SEM) and Transmission Electron Microscopy (TEM) characterize the mineral phases responsible for self-healing, offering a detailed understanding of the microstructural evolution within damaged regions. These findings highlight the potential of self-healing coatings to preserve the mechanical integrity of stone substrates, offering a promising solution for sustainable CH conservation.

By emulating historical self-repair mechanisms, our coating system establishes a foundation for resilient and proactive heritage protection strategies. This research not only advances CH preservation technology but also contributes to innovative materials that extend the lifespan of cultural heritage assets.

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4:15pm **AA3-WeA-12 Harnessing Atomic and Molecular Layer Deposition for Advanced Membrane Technologies in Water Treatment**, ***Eran Edri,*** Ben Gurion University Be’er Sheva, Israel

Advanced membrane technologies are essential for addressing pressing global water treatment challenges, including water softening, selective desalination, and biofouling mitigation. This work explores how atomic layer deposition (ALD) and molecular layer deposition (MLD) can enhance membrane performance and stability across diverse applications while preserving water permeability. We first investigated the ion selectivity of commercial thin-film composite nanofiltration (NF) membranes by applying ethylene glycol–aluminum (EG-alucone) coatings via MLD. Systematic variation in the number of deposition cycles allowed the active layer to be successively infiltrated, inflated, and coated with an alucone film. These structural and charge modifications significantly improved sodium selectivity over divalent cations, reducing water hardness in synthetic and natural brackish water samples with minimal permeability loss. This study demonstrates how MLD coatings, precisely tuned to target dielectric, steric, and electrostatic ion-exclusion mechanisms, can enable the rational design of NF membranes for enhanced selectivity. In a second application, MLD was extended to develop monovalent-selective cation exchange membranes (MVS-CEMs) critical for energy-efficient electrodialysis. By precisely controlling the thickness of ultrathin alucone layers on CEMs, high monovalent selectivity was achieved without adding significant transport resistance. This approach overcame the conventional trade-off between selectivity and resistance, advancing cost-effective brackish water desalination technologies that retain essential nutrients. Finally, ALD was employed to mitigate biofouling in reverse osmosis (RO) membranes by applying uniform aluminum oxide (Al_2O_3) coatings. Optimization of the coating thickness significantly enhanced ozone resistance, enabling ozone-based disinfection to prevent biofilm formation during extended flow-cell experiments. The protective Al_2O_3 barrier mitigated biofouling while maintaining the desalination performance of the underlying RO membranes.

These studies underscore the transformative potential of ALD and MLD in tailoring membrane surfaces for application-specific selectivity, chemical stability, and energy efficiency. This work paves the way for sustainable and versatile water treatment technologies, demonstrating how precise nanoscale surface engineering can address critical challenges in global water management.

4:30pm **AA3-WeA-13 Surface Modification of Additive Manufacturing Feedstocks**, *Chris Gump, Brandon Castro, Joeseph Gauspohl,* Forge Nano*; Anthony Manerbino, Jeremy Iten,* Elementum3D*; Guillermo Rojas, Casey Christopher, Markus Groner, Dane Lindblad, Brandon Woo, **Arrelaine Dameron,*** Forge Nano

Additive Manufacturing (AM), also called 3D printing, constructs objects from a digital model, typically by depositing and solidifying material layer by layer. AM processes that utilize powder feedstocks include laser powder bed fusion and binder jetting. AM can manufacture objects with intricate internal structures and/or small features that cannot be easily or economically fabricated by top-down machining methods or when these machining tools are not available. However, the number of alloys that can be printed successfully with superior mechanical properties by AM is limited. Possible reasons include 1) the crystal structure/internal stresses of the as-printed part leads to adverse mechanical properties, 2) the feedstock powders do not flow well and are difficult to print uniformly leading to part defects, or 3) high reflectivity of the feedstock preventing effective absorption of input energy, 4) the powder is sensitive to ambient air and has a limited shelf life or powder degradation leads to chemical inclusions and defects. These material deficiencies can be mitigated by nanoscale surface coatings that are chemically precise and uniformly distributed. We demonstrate ALD Al_2O_3, SiO_2 and Y_2O_3 coatings on AlSi10Mg, Ti64, and SiC powders at gram and kg scale. ICP, LECO, and STEM imaging and elemental mapping demonstrated successful surface modification. These coatings increased feedstock oxidation resistance by acting as a moisture and oxygen barriers, and increased powder flowability, demonstrated by a reduction in Hall Flow time. 3D printed cubes and bars from each material were tested ‘as printed’ and after hot isostatic pressing. Parts using the ALD-coated material had the highest density, yield stress, and UTS, while also having the lowest surface roughness.

4:45pm **AA3-WeA-14 Closing Remarks and Awards**,

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